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Detroit
Mich.

REPORT

OF THE

STATE BOARD OF GEOLOGICAL SURVEY

FOR THE YEARS 1891 AND 1892

TO WHICH ARE APPENDED

EXHIBITS

Setting Forth the Expenses of the Survey from its Inception to November 22, 1892, Exclusive of the Cost of Publication. Also the Reports of Dr. Carl Rominger for the Years 1881-2 and 1882-3; of Mr. Charles E. Wright for the Years 1885-8; of Dr. M. E. Wadsworth for the Years 1889, 1890, 1891, 1892, made to the State Board of Geological Survey for the Years Named; also a Provisional Report by Dr. M. E. Wadsworth, State Geologist, upon the Geology of the Iron, Gold and Copper Districts of Michigan.

BY AUTHORITY

LANSING
ROBERT SMITH & CO., STATE PRINTERS AND BINDERS
1893

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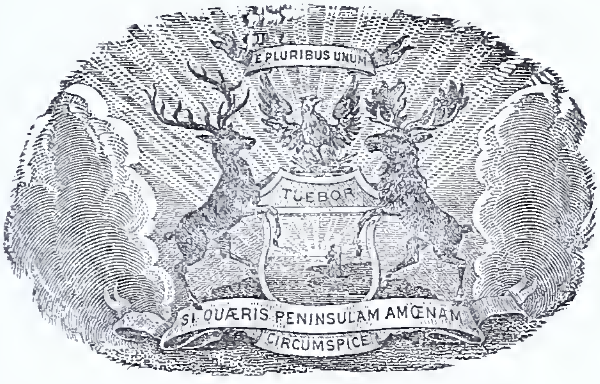

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1893.

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ROBERT R. BLACKER, Secretary of State
Lansing, Michigan.

REPORT

OF THE

STATE BOARD OF GEOLOGICAL SURVEY.

To the Legislature of the State of Michigan:

In compliance with section 5472 of Howell's Annotated Statutes we lay before you the following report:

PROVISIONS OF LAW.

The law provides that this Board shall make an annual report, but makes no provision as to the official or body to whom the report shall be made. The board is composed of the Governor of the State. the Superintendent of Public Instruction and the President of the State Board of Education, and unless the first two named officers are reëlected to succeed themselves, the entire membership of the Board is changed every two years. If the law contemplated the making of the report to the Governor, he would be simply making a report to himself of those matters with which he was already acquainted. If it were to be made to the Legislature the law should so specify. Doubtless the indefiniteness existing upon this point is one of the reasons why the law has never, so far as we are able to learn, been complied with. The complete removal of all members of the Board at such frequent intervals is another reason. The main reason, however, seems to have been the neglect of the Board to do so.

As before intimated, we have been unable to find any report made since the publication of the last volume of the survey in 1881, and for this reason when we entered upon the discharge of our duty, we found but little if any help was to be obtained from the meager records obtainable. We found that a great deal of money had been expended and but comparatively little work accomplished for such expenditure. It has been with much difficulty that the data for an intelligent report could be gathered, and had it not been for the fact that one of our number has taken an unusual interest in the progress of the Survey for many years, we should have been unable to lay before you as much as we now do.

While it is not our desire to criticise others, still it does seem that the members of the Board during the time above specified have felt that their duty had been done when they had employed a State Geologist. For several years last passed it seems to have been left to him to determine when, where and how he should conduct the work of the Survey without any supervision whatever, while the reports made from time to time to the Board by the State Geologist were filed away and no use made of them.

The duties of the Board are succinctly set forth in the law, and are all that could be desired if properly observed. The law reads as follows:

> "They (the Board) shall control and supervise the continuance and the completion of the geological survey of the State; and for that purpose they may from time to time appoint such person or persons to assist in making said survey as may be deemed necessary; the length of time, and the location and locations where said persons shall be employed, shall be determined by said Board."

It would, however, be unjust to all concerned were not the fact mentioned that the death of State Geologist Charles E. Wright in 1888 is claimed to have deterred the work of the survey very materially, and to a certain extent this is true, but it is also true that an examination of the work done by him shows that it was extended over so wide a territory, and the data gathered by him were in so incoherent and incomplete condition that he alone would have been able to have used them to much advantage. While his great ability, experience and industry fully warrant all the encomiums which have been bestowed upon him, yet the condition of the Survey at the time of his death serves to emphasize the criticism that the Board was derelict in its duty in failing to comply with the last clause of he law above cited.

It has been found necessary, to a great extent, to do over again the work upon which he had been so long engaged, but which, had he lived to complete the same or had the records of the survey been brought up to date, would have been unnecessary.

During the past two years the efforts of this Board have been directed to securing results for publication.

PRESENT CONDITION OF THE WORK.

Upon the death of Mr. C. E. Wright, who was also a member of the Board of Control of the Mining School, great stress was brought to bear upon the Board, as we are informed, to appoint some one as State Geologist, who could take up the work where he had dropped it, and it was finally concluded that Dr. M. E. Wadsworth, Director of the Michigan Mining School, was the proper person to employ, and an arrangement was entered into, between the Board of Control of that institution and the State Board of Geological Survey, whereby Dr. Wadsworth should be permitted to manage that institution and act as State Geologist at the same time. It was also arranged that members of the faculty of the Mining School should also be assistants to the State Geologist.

Dr. Wadsworth at that time stated it to be his opinion that by this arrangement the work marked out by Mr. Wright could be completed in four years. Subsequent events, however, have proved him to have been in error as to the time, as this Board is now informed by him that it will require a longer period.

It is true, that the unwisdom of uniting the school and the survey in this manner was brought to the attention of the Board; but the inadequacy of the means provided for carrying on the Survey rendering it impossible for the Board to employ men, furnish rooms and equip a suitable laboratory caused the argument, that the interests of the School and the Survey were, in a measure, identical, and that each would aid the other in accomplishing the objects sought, to prevail.

The interest of the School in such an arrangement is tersely set forth by Dr. Wadsworth in the report of the Director and Treasurer of the Michigan Mining School, published in 1891. Speaking of his connection with the survey, he says:

> "The Director does not desire to give up his instruction, since he desires to see developed from the data of the Geological Survey a department of practical geology that will assist in the development of the State and will train men for intelligent exploration. This is a proper function of the School, and he sees no way of accomplishing it unless the present union of the School and Survey continues, since either alone is too weak to do the work as it should be done."

From the above it will be seen that the State Geologist conceives that the Survey, at least until recently, has been used as a means for the advancement of the Mining School. At present, however, it may be stated that conditions are somewhat altered, and the Survey is now advancing to definite results. It is estimated that under the present arrangements it will require about two years to complete the work left by Mr. Wright, and such new work as has since been undertaken in connection therewith.

Dr. Wadsworth has the Survey thoroughly organized, and has surrounded himself with intelligent assistants, and so far as the *time given* to the Survey will permit, he is making commendable progress. It should also be remembered that since May, 1889, the Mining School has furnished to the Geological Survey a room, free of rent, about twenty-five by thirty feet in size; in which all the indoor work of the Survey has been performed, and in which is now stored all the property of the Survey, except manuscripts and published volumes, and property connected with the field work.

It has also furnished laboratories for such work as was required to be done in them. From this it will readily be seen that there is a disposition upon the part of the Mining School to furnish an equivalent to the State under the arrangement made, and we recommend that, until the work now in progress is completed, this arrangement be continued, provided, the Survey can secure at all times its just proportion of time and service.

During the period since Mr. Wright was appointed State Geologist, a great deal of money has been expended, as appears from Exhibits "A" and "B", hereto attached, and definite results should have been secured and made public long prior to this date. Other expenditures are shown in Exhibit C.

The expenditures during the three years of Mr. Wright's occupancy of the position of State Geologist were practically lost to the State by reason of his death before he had reduced any of his work to permanent form. We do not feel, however, that it was his fault so much as it was the fault of the Board, in not requesting material for publication as fast as the field work was done.

The results secured during the past ten years have lost much of their value to the general public for want of timely publication. Many examinations and explorations, made during that time, would have been of great aid in developing the resources of the territory surveyed, could those interested in such development have had before them the information acquired by the Survey.

From examinations of the reports of Dr. Carl Rominger, who preceded Mr. Wright as State Geologist, made to the Board of State Geological

Survey for the years 1881-2 and 1882-3 (see Exhibits D & E) and those of Mr. Wright, made to the State Geological Survey for the years 1885-88 (Exhibit F), it will be seen that the survey was being pushed in a somewhat cursory manner, yet along a line of considerable value to the general public; but the knowledge acquired seems to have been known only to the persons of the Survey and to a few persons interested in the development of the mining interests in the Upper Peninsula.

From the Annual Reports of Dr. Wadsworth to the Board for the years 1889, 1890, 1891 and 1892 (Exhibits G, H, I and J), a good idea may be gained of the progress of the work since he became State Geologist. From this it will be seen that he has been gathering up the lost threads dropped by reason of Mr. Wright's death and undertaking such new work as may lie in the direct line of that already commenced.

We also append a provisional report of Dr. Wadsworth's upon the geology of the iron, gold and copper districts of Michigan, stating (see Ex. K) succinctly, the history of the work and the character of the publication about ready to be made. This will convey to the Legislature and the general public, if properly distributed, a good idea of the results which have been secured through the work of the Survey, without reference to the scientific and economic questions which have been determined.

The only criticism to be made is that it seems very unfortunate that these results were not published as they were obtained. As above intimated the reason for non-publication existed in the fact that no portion of the work attempted was completed and made ready for publication except that which Dr. Rominger prepared showing the progress of the work from 1881 to 1884. This should have been published at that time, and why it was not is difficult to conceive.

This manuscript was placed in the hands of the Board March 11, 1885, and was intended for Vol. V. of the Survey. It will now appear as a portion of that volume.

In addition to the material which accompanies this report, there is now nearly ready for publication a volume of about five hundred pages, which will make Vol. V. in the series of reports. This volume will contain, first, the report of Dr. Rominger referred to above; second, the Geology of the Marquette District of Michigan; and third, the gas and salt wells of Michigan, with sections, maps, etc., illustrative of the same. Could these reports have been published several years ago, as it seems to us they should have been. they would have proved of great value in the development of the vast industries which have been created for the production of salt, iron, gold and copper, and would have prevented the waste of much capital and energy in useless exploration and experimentation. It must be admitted that the Survey has gained most of its information from the development of mines of salt and of copper and other minerals, instead of giving information which has led to their development.

Lest we should be considered unjust in making these criticisms, we quote from a letter of Mr. Wright, written on February 12, 1885, in reply to a request to give his opinion of the Geological Survey of Michigan to the then Board, in which, among other things he stated:

> "Since Messrs. Brooks', Pumpelly's and Rominger's Report of 1869-72 the Geological Survey has been continued in a very limited way. Major Brooks' Report of the Iron District has proved of great value in the development of our iron ore deposits. It has saved many times its cost by indicating to explorers where to look for iron ore veins. The disadvantages under which the work was done were many compared to the present advantages of transportation, developments, etc. At that time the Geological Survey

was leading the way, but now, I regret to add, it is far behind the development and discoveries made by individuals and corporations."

After discussing at some length the work as it was then in progress, he says:

> "If our explorers and corporations would work in harmony and have a central office where all the geological data could be collated and results deduced therefrom there would not then be that economic necessity for a Geological Survey. These same parties, however, would be willing to impart to the State Geologist their facts and would gladly receive any suggestions he might make them.
>
> "In the Iron and Copper Districts many valuable facts are constantly being developed which, if properly collated, would prove of intrinsic scientific value and would greatly assist the future development of our mineral resources. There have been hundreds of diamond drill holes put down to depths varying from two to ten hundred feet, not only in the above districts but also in the coal and salt districts of the Lower Peninsula; also for artesian wells. This kind of data is geologically the most valuable, for it affords a cross-section of the different strata unacted upon by the various elements to which surface ledges are exposed.
>
> "In the above comments on the Geological Survey it is not intended to criticise Dr. Rominger's work, but rather to call attention to what needs to be done. There can be no question but that the work should have been prosecuted more vigorously.
>
> "The office of the Geological Survey should be of such a character that all geological facts obtained by explorers and companies would naturally gravitate to it. They bringing their specimens and knowledge to the State Geologist and exchanging them for the best information he could afford; thereby instead of having three or four to assist in collecting data, he would have as many dozen."

Not long after writing the above Mr. Wright was appointed State Geologist, and the natural inference would be that the remedies pointed out by him would have been adopted and enforced by the Board. But such was not the case. While Mr. Wright may have done his share of the work, there was, as is above intimated, no definite conclusion to any portion thereof, and for three years the bulk of his work was known only to himself, and upon his death was almost entirely lost to the State, whereas, had the Board of State Geological Survey made its annual reports as the law requires, he would have been obliged to have put his investigations and their results into form for publication.

During the years 1888–1892 the work done has been largely expended in recovering this lost ground, and each year has seen some definite progress, but the results have remained unpublished until the present.

The work relative to salt wells is now nearly completed. That relative to what is known as the Marquette Range is well under way to completion. Much ought yet to be done to complete the Survey of the Copper region, but if what has been done is of any immediate value, it must be published at once. Work is being pushed, as fast as under present arrangements it can be, in the Gogebic district, and thence to the State Line.

The Southern Peninsula has, during many years received but little attention from the Survey. This has been owing in part to the fact that the development of the large mineral interests in the Northern Peninsula has monopolized the attention of those most interested in the Survey; but in part also because the State Geologist has invariably, from the inception of the Survey, been paid for and required to give a portion only of his time to the work of the Survey, an arrangement which the small amount of the appropriation has rendered almost imperative.

As stated above, much of the matter now ready for publication has lost the interest and value it would have had if more timely publication had been made, and the question naturally arises, "Why, then, publish this portion of the work at all?" The answer is that in no other way can a permanent record of these matters be secured and thereby preserved to the State a history of its resources.

Another and very pertinent reason for publication exists in the fact that the progress of the Survey has disclosed many important geological facts which for their scientific, as well as their economic value, ought not to be lost. The world possesses no region where the geological student is brought more intimately into contact with novel questions relative to rock formations. and many of the discoveries made will prove of permanent value, and will aid capital for many years to come.

There is still another reason which deserves mention. Dr. Wadsworth and several of his present assistants are entitled to have credit given them for such original work as they have done in the discharge of their several duties, and in no other way can this be secured to them. This Board feels that while it cannot approve of the dilatoriness manifested in the prosecution of the survey, it has no right to criticise the employés of the Board for matters for which they ought not to be held responsible, and to refuse publication of the results of their work would amount to a gross injustice.

PROPERTY OF THE BOARD.

We find there has been great waste of the property of the Board. Two thousand copies each of the First, Second, Third and Fourth Volumes of the Survey were published, and five hundred extra copies of a portion of the Second Volume known as the "Iron-bearing Rocks," and five hundred sets of maps to accompany the same. Today there are left nine copies of the First Volume, twelve copies of the Second Volume, thirty copies of the Third Volume, one hundred and seventy-nine copies of the Fourth Volume. Of the "Iron-bearing Rocks" there are left 216 volumes and 200 sets of maps belonging to the "Iron-bearing Rocks." Of these, nine copies of the First Volume, seven copies of the Second Volume, ten copies of the Third Volume, seventeen copies of the Fourth Volume, one copy of the "Iron-bearing Rocks" and nine charts are in the State Library, and nineteen volumes of the "Iron-bearing Rocks," nine copies of Volume Three, sixteen copies of Volume Four and nine sets of maps are in the Governor's office. Those in the State Library are what remain of fifty sets placed there by resolution of the Board a number of years ago. As is seen, they are nearly all scattered, but upon what authority we do not know.

It will also be seen that there is now in the possession of this Board no complete set of the reports. That they have been wantonly wasted cannot for a moment be disputed. Our predecessors for the year 1874 passed a resolution that certain sets be sent to New York and placed on sale. Whether any were sent, and, if so, what disposition was made of them or of the proceeds, if any, we find no record. Certain sets were also placed on sale in Detroit. The only trace we can find of these is in a bill of "Richmond & Backus," where we find credit given for two sets sold. Soon after the first three volumes were published there seems to have been a fear on the part of the Board that the Reports could not easily be gotten rid of, and it was voted to give a set to almost everyone of the slightest public character. Later the Board discovered the error committed, and an attempt was made to correct it, but too late to save the State from an irreparable loss.

The room in which these volumes were stored we found upon the third floor of the capitol, and soon after the assemblage of the Legislature of 1891 we were informed that members were entering it and helping themselves. We have also been informed that it has been the custom for the members of the several Legislatures of the past to help themselves to copies of the Survey, if they desired. Complete sets of the Survey would now command a ready sale at $50 a set. At the beginning of the year 1883 the Board was in possession of 460 full sets of reports. Now it has not one. The cost of publication to the State has been nearly $30,000.00, which sum does not appear in the exhibits of expenditures, except in part under items "charged out," in Exhibit C.

The above statement of facts needs no comment. We have now gathered all that remains of the published volumes together, and placed them, except those in the Governor's office and the State Library, where the law demands that the property of the Survey should be placed, in the custody of the Superintendent of Public Instruction. There they should be kept, and he should be held to a strict accountability for every volume and set of maps placed in his charge. The maps are still in the old room for want of a suitable place to store them where the books are.

The other property belonging to the Board, except manuscript ready for publication, is set forth in Appendix L. hereto annexed. Much of this is of the most valuable character.

The law provides that the specimens prepared during the progress of the Survey should, when completed, be placed in the State Library as a permanent exhibit. We suggest that this is not its proper destination. A commodious fire-proof room should be provided, well lighted, to which the student in geology could, under proper restriction, have access, for the purpose of examining all microscopic and other specimens collected by the Survey. Some of these specimens are very rare and of great permanent value. A complete catalogue of these specimens is now ready for publication.

A careful investigation shows that the Survey has owned considerable other property, but it appears that upon the death of Mr. Wright no property could be found belonging to the Survey except the manuscript of Dr. Rominger, to which reference is made above; one old microscope, Mr. Wright's field and note books, and a few ore and rock specimens and such published reports as were left. Diligent search has not discovered the whereabouts of this lost property. There is no doubt it was lost through want of some one to look after it.

Since Dr. Wadsworth was appointed State Geologist, the law relative to the distribution of specimens of rocks and ore among the schools of the State has been partially complied with.

The whole business of the Survey, unless looked after more closely in the future than in the past, is apt to be prolonged to unreasonable length. Proper energy ought to close the work of the Survey at no distant period. This Board feels that its whole duty to the State of Michigan is not done unless it advises the Legislature that the recommendations contained herein are of vital worth, and ought to be adopted.

UNITED STATES SURVEY.

Arrangements have been made through the agency of Dr. Wadsworth with the United States Geological Survey, whereby this State will be permitted, upon terms very advantageous to itself, to have the results obtained by it put into the possession of the Michigan Survey, and access be given the State Geologist to the topographical sheets of the United States Survey in Michigan, as soon as they are drawn. The United States Survey also offers to make a division of the geological work in such a way that the Federal survey will undertake the purely paleontologic work in that portion of the State covered by its work, while the State Survey shall assume all purely economic investigations.

This arrangement, if carried out, will prove of great value to the State, and will tend to hasten the completion of the work. Dr. Wadsworth's aid in this direction cannot be too highly estimated and if his entire time could be secured to the Survey the State would be a great gainer thereby. If his time cannot be secured, that of some other competent geologist should be, and a sufficicient appropriation should be made to secure this result.

RECOMMENDATIONS.

This Board recommends:

1. That second editions of the Reports be published in the same form as the first editions, so that the whole number of complete sets shall equal 1,000.
2. That an edition of 4,000 of Volume V be published, to correspond with the volumes already published.
3. That a room in the Capitol be set aside for the Geological Survey, and that all the property belonging to the Survey, not in actual use, be kept therein.
4. That an additional member be added to the Board, whose term of office shall continue for five years.
5. That the law creating the Board be so changed as to embody the amendments above suggested.
6. That the appropriation for the conduct of the Survey during the next two years should at least be doubled, so as to secure the entire time of a competent geologist and well equipped assistants.
7. We earnestly desire that an appropriation be made, say of $12,000.00, to be used, so much thereof as is necessary, to publish Volume V. and so many copies of the second editions of the other volumes as shall meet the requirements in recommendation 1.

CONCLUSION.

Should the Legislature permit the survey to continue in the future as it has in the past, no definite limit can be fixed as to the time when the Survey will be completed. The members of the Board are all such *ex officio*. The Governor of the State of Michigan is a hard-worked official. His duties are many and onerous. The Superintendent of Public Instruction has but a meager salary, and while he receives but $1,000 per annum for his services, the State receives from him in the ordinary discharge of his duties several times that amount. There is no Board in the State, perhaps, upon whom so many varied duties devolve as upon the State Board of Education, and the President of that Board, if he does his full duty, cannot be expected to spend much time upon any other board. The present incumbent of that office has given more than six weeks of his time to the Survey and has received therefor $45.00 in per diem.

The only way by which the Geological Board can be properly looked after is to have a member belonging to it whose sole duty shall be to attend to the matters of this Board.

We are unable to see any reason for the existence of a Commissioner on Mineral Statistics independent of the Geological Survey. The work of that officer naturally falls under the supervision of the Survey, and could be better done by it than by such Commissioner. Should that office, therefore, be united with the Survey, and an additional member be added to the Board of Geological Survey, whose duties should be to discharge the functions now performed by that officer, great good would accrue to the State. The Geological Survey would be properly looked after, and equally valuable results obtained relative to mineral statistics, with but little if any additional expense to the State.

In submitting this report to the Legislature we do not wish to be understood as passing an adverse judgment upon the action of our predecessors; we have stated the facts as we find them. Such records as were kept disclose that the gentlemen who at differant times have been members of the Board have felt that matters were not progressing as they ought, and have always seemed anxious to put the survey upon a better basis. But all their efforts seem to have ended in calling before them whoever occupied the position of State Geologist, and after listening to what he had to say, dismissing him with the advice to push the Survey as vigorously as possible. Of course the result was that they gained no personal knowledge of the work being done, and possibly having no definite knowledge of what ought to be done, believed that nothing better could be done.

No good to the State can arise from dwelling upon the past conduct of the Survey, but it is imperative that measures be taken at once to continue the Survey actively and along such lines as will produce definite results at more frequent intervals. Unnecessary delays should be rendered impossible. Persons employed to do the work of the Survey should not be permitted to occupy themselves with other interests which concern them more than do those of the survey. This Board, or some member of it at least, should be selected to give more time and attention to its work, and he should be sufficiently acquainted with the work sought to be accomplished to render his judgment of value to the Board.

The suggestion made above relative to combining the duties of the Commissioner on Mineral Statistics with the work of the Survey seems to us a feasible solution of the whole question, and we therefore urgently recommend its adoption.

Respectfully submitted,
EDWIN B. WINANS,
FERRIS S. FITCH,
S. S. BABCOCK,
Board of Geological Survey.

STATEMENT OF THE EXPENDITURES

AT THE

OFFICE OF THE STATE GEOLOGIST

FROM MAY 1, 1885, TO DECEMBER 31, 1887.

CHARLES E. WRIGHT, STATE GEOLOGIST.

EXHIBIT A.

STATEMENT OF EXPENDITURES FOR 1885.

Field Work.

Months.	Wages.	Supplies.	Transportation.	Monthly totals.
May				
June	$190 50	$62 20	$10 00	$262 70
July	225 00	26 92	15 50	267 42
August	209 00	33 51	33 85	276 36
September	182 50	11 58	17 05	211 13
October	186 00	23 56	31 60	241 16
November	24 75			24 75
December	1,387 33			1,387 33
Totals	$2,405 08	$157 77	$108 00	$2,670 85

Office Work.

Months.	Wages.	Supplies.	Rent.	Monthly totals.
May		$85 80		$85 80
June		120 00		120 00
July		168 00		168 00
August		97 60		97 60
September				
October	$28 00	36 50		64 50
November	24 00	30 00	$9 00	63 00
December	26 50			26 50
Totals	$78 50	$537 90	$9 00	$625 40

Total expenditures from May 1, to December 31, 1885	$3,296 25

STATEMENT OF EXPENDITURES FOR 1886.

Field Work.

Months.	Wages.	Supplies.	Transportation.	Monthly totals.
January				
February				
March			$142 15	$142 15
April				
May	$283 50	$124 18	20 05	427 73
June	1,375 00	33 85	42 00	1,450 85
July	394 70	127 85	36 00	558 55
August	418 00	22 02	2 50	442 52
September	345 50	62 21	38 70	446 51
October	306 20	83 92	12 75	402 87
November	136 50	21 58	5 15	163 23
December	1,000 00		92 61	1,092 61
Totals	$4,259 40	$475 61	$391 91	$5,126 92

Office Work.

Months.	Wages.	Supplies.	Rent.	Monthly totals.
January	$189 50	$17 35		$206 85
February	106 75	9 55	$10 00	126 30
March	128 25	27 19		155 44
April	105 87	18 69	10 00	134 56
May	26 00			26 00
June	25 00			25 00
July	21 00	19 00	10 00	50 00
August	19 50			19 50
September	22 50			22 50
October	12 50			12 50
November	22 00	17 37		39 37
December	133 64	1 74	20 00	155 38
Totals	$812 51	$110 89	$50 00	$973 40
Total expenditures for 1886				$6,100 32

STATEMENT OF EXPENDITURES FOR 1887.

Field Work.

Months.	Wages.	Supplies.	Transportation.	Monthly totals.
January				
February			$2 55	$2 55
March				
April		$50 70	2 00	52 70
May	$460 00	27 26	56 70	543 96
June	1,388 00	110 13	18 25	1,516 38
July	485 00	73 90	38 50	597 40
August	432 00	28 31	25 25	485 56
September	415 00	81 63	161 75	658 38
October	329 50	116 78	98 66	544 94
November	108 00	20 62	37 85	166 47
December	1,000 00	20 30	49 03	1.069 33
Totals	$4,617 50	$529 63	$490 54	$5,637 67

Office Work.

Months.	Wages.	Supplies.	Rent.	Monthly totals.
January	$178 80	$28 95	$10 00	$217 75
February	110 90		10 00	120 90
March	110 37	10 00	10 00	120 37
April	47 50		10 00	57 50
May	26 00	31 21	10 00	67 21
June	25 00	5 00	10 00	40 00
July	26 00	11 25	10 00	47 25
August	29 25	12 00		41 25
September	32 50	36 84		69 34
October	32 00	18 00		50 00
November	42 75		20 00	62 75
December	105 00		17 50	122 50
Totals	$766 07	$143 25	$107 50	$1,016 82
Total expenditures for 1887				$6 654 49

Recapitulation.

Expenditures for 1885	$3,296 25
“ “ 1886	6,100 32
“ “ 1887	6,654 49
Total	$16,051 06

STATEMENT OF THE EXPENDITURES
AT THE
OFFICE OF THE STATE GEOLOGIST.

MAY 1, 1888, TO JANUARY 1, 1892.

BY M. E. WADSWORTH.

EXHIBIT B.

STATEMENT OF EXPENDITURES.

1888.

Months.	Salaries.	Office expenses.	Field expenses.	Totals.
May	$341 00	$68 20	$91 41	$500 61
June	967 50	82 50	17 00	1,067 00
July	993 75	47 25	103 10	1,144 10
August	546 75	3 07	176 67	726 49
September	534 50	35 00	213 00	782 50
October	813 83	62 10	71 35	947 28
November	116 20	11 60	20 40	148 20
December	433 33	26 12		459 45
Total	$4,746 86	$335 84	$692 93	$5,775 63

1889.

Months.	Salaries.	Office expenses.	Field expenses.	Totals.
January	$243 34	$33 75		$277 09
February	346 37	44 14		390 51
March	406 04	81 00		487 04
April	417 69	33 65	$123 15	574 49
May	811 20	2 15	66 47	879 82
June	781 66	29 30	176 86	987 82
July	838 17	32 00	104 49	974 66
August	897 91	6 80	131 60	1,036 31
September	849 41	5 34	162 66	917 41
October	351 67		1 14	352 81
November	406 66	40		407 06
December	420 13	122 50		542 63
Total	$6,670 25	$391 03	$766 37	$7,827 65

1890.

Months.	Salaries.	Office expenses.	Field expenses.	Totals.
January	$426 16	$4 78		$430 94
February	387 16	9 25		396 41
March	428 62	8 21		436 83
April	413 16	11 40		424 56
May	451 66	2 50	$14 30	468 46
June	391 67		16 05	407 72
July	445 66	94 38	7 55	547 59
August	520 66	60	22 00	543 26
September	584 67		55 31	639 98
October	659 16		127 85	787 01
November	494 16	31 27	31 45	556 88
December	533 67	50		534 17
Total	$5,736 41	$162 89	$274 51	$6,173 81

1891.

Months.	Salaries.	Office expenses.	Field expenses.	Totals.
January	$54 67	$70 34		$125 01
February	601 17	5 20	$0 80	607 17
March	791 66			791 66
April	728 91	36 82		765 73
May	581 50	194 75	77 40	853 65
June	800 00		78 10	878 10
July	499 50	1 50	65 63	566 63
August	422 00		43 63	466 13
September	558 33	15 22	48 99	622 54
October	464 27	21 60	140 70	626 57
November	498 83	2 15	147 78	648 76
December	360 78	505 34		866 12
Total	$6,361 62	$852 92	$603 03	$7,818 07

SUMMARY.

1888	$4,746 86	$335 84	$692 93	$5,775 63
1889	6,670 25	391 03	766 37	7,827 65
1890	5,736 41	162 89	274 51	6,173 81
1891	6,361 62	852 92	603 03	7,818 07
Total	$23,515 14	$1,742 68	$2,336 84	$27,595 16

GENERAL EXPENDITURES

OF THE

GEOLOGICAL SURVEY.

1837 TO 1845.

1859 TO 1862.

1870 TO JULY, 1891.

FROM THE STATE AUDITOR'S OFFICE.

EXHIBIT C.

Geological Survey in account with the State of Michigan.

DR.

Years.	For what drawn.	Amount.	Amount.
1837 1838	General purpuses of Survey		$16,026 00
1839	" " "		8,329 95
1840	" " "		7,161 37
1841	" " "		6,219 55
1842	" " "		1,263 13
1842	Salary of State Geologist	$782 87	
1842	Salary of State Topographer	624 53	
1842	Incidental expenses	1,032 82	
			2,440 22
1843	Salary of State Geologist	1,000 00	
1843	Salary of State Topographer	800 00	
1843	Incidental expenses	220 47	
			3,002 47
1844	Salary State Geologist	1,000 00	
1844	Salary State Topographer	800 00	
1844	Engraving expenses	338 16	
1844	Incidental expenses	397 30	
			2,535 46
1845	Salary State Geologist (to July)	500 00	
1845	Salary State Topographer	639 42	
1845	Engravings	658 92	
1845	Incidental	34 54	
			1,832 88
Total			$32,829 03
Returned to State			7,170 97
Total			$40,000 00

Geological Survey in account with the State of Michigan.

CR.

Years.	Appropriation.	Amount.
1837	General purposes	$3,000 00
1838	General purposes	12,000 00
1839	General purposes	12,000 00
1840	General purposes	12,000 00
1841	No appropriation, there being balance to credit Survey	
1842	No appropriation, there being balance to credit Survey	
1843	No appropriation, there being balance to credit Survey	
1844	For engravings	500 00
1845	For engravings	500 00
Total		$40,000 00

Geological Survey.

Year.	Amount Drawn.	Amount charged out.*	Amount appropriated.	Act.
1859	$2,000 00		General fund	206, 1859
1860	3,000 00		General fund	206, 1859
1861	750 00			64, 1861
1862	250 00			
1870	80 91			
1873	1,000 00			179, 1871
1874	5,000 00		$8,000 00	179, 1871
1875	2,000 00		8,000 00	179, 1871
1875	6,573 00			179, 1871
1876	5,000 00		8,000 00	179, 1871
1877	5,000 00	† $2,919 09 ‡ 7,927 00	8,000 00	179, 1871
1878	1,300 00	5,500 00	8,000 00	179, 1871
1879	1,500 00	6,388 33	8,000 00	179, 1871
1880	4,000 00	4,895 75	8,000 00	179, 1871
1881	2,453 76	5,462 16	8,000 00	179, 1871
1881	6,000 00			
1882	2,100 00	1,064 03	8,000 00	179, 1871
1883	4,000 00	5,900 00	8,000 00	179, 1871
1884	2,000 00	4,000 00	8,000 00	179, 1871
1885	4,000 00	6,000 00	8,000 00	179, 1871
1886	4,000 00	2,000 00	8,000 00	179, 1871
1886	2,000 00			
1887	2,000 00	4,000 00	8,000 00	179, 1871
July 1887	2,000 00			
to July 1888	6,665 44	1,344 56	8,000 00	179, 1871
July 1888				179, 1871
to July 1889	8,000 00		8,000 00	179, 1271
July 1890	8,397 36	1,602 64	8,000 00	179, 1871
to July 1891	5,738 93	1,604 29	8,000 00	179, 1871
July, 1891 to July, 1892	7,950 44	49 56	8,000 00	179, 1871
July, 1892 to Nov. 22, 1892	4,849 49	3,150 51	8,000 00	179, 1871
Total	$109,599 33	$63,207 92	$160,000 00	

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* Or returned to the State.
† Act No. 64, 1861.
‡ Act No. 179, 1871.

The sums represented previous to 1887 include amount drawn in Calendar year, the book-keeping method having been changed in 1887. The figures since have reference to the fiscal year, i. e., July 1 to June 30, inclusive.

REPORT

OF THE

STATE GEOLOGIST

FOR

1881—1882.

BY CARL ROMINGER

4

EXHIBIT D.

Ann Arbor, April 28, 1882.

Honored Mr. V. B. Cochran,
Secretary of the Board of the Geological Survey of Michigan:

Dear Sir—In compliance with your request for a brief statement of work I intend to follow during the coming season in the consideration of the Survey, I take the liberty to propose first to revisit, in a cursory way, the numerous places in the Menominee and Marquette districts where explorations have been going on last year and are going on now, in order to collect all scientific information obtainable from the progress of such work, but also on the other hand to use this so gathered information immediately for the benefit of the explorers by elucidating their knowledge of the structure of the fields on which they operate and by counseling them in special cases. The usefulness of such a plan of constant supervision of the work of the miner in its progress is well acknowledged by the inhabitants of the mining districts.

Among other work performed during the last season, the State Geologist made a cursory examination of the Lake Gogebic district, extending his travels to the east end of Sunday Lake. A belt of iron-bearing rock strata is known to extend across the center part of town tier 47, from Lake Gogebic westward to Montreal River. East of Sunday Lake I have gone over that belt, limited on the north side by copper-bearing trap rock and on the south side by granitic and dioritic rocks, but as far as I was able to observe, no valuable iron ore deposits exist in this part of the rock belt. West of Sunday Lake the strata must be more impregnated with iron oxide, as various mining companies are lively at work there in exploring for iron ore, and, as reports go, fair seams of iron ore have been discovered.

The region, not only interesting by its iron-bearing rocks but still more so by the occurrence of the copper-bearing series, in close contiguity with the former, and so far only little examined by geologists, promises to be a fine field for gathering new and valuable information in geology. Its remoteness from inhabited places makes this district very difficult of access, but as at present numerous exploring parties are engaged there, the facilities for geological examination are now much greater than they were before or perhaps than they will be hereafter. In consideration of this favorable circumstance, I propose, as soon as I am through with the re-examination of the Marquette and Menominee districts, to go and spend the remainder of the season with the examination of the country between Black River and Montreal River. This examination promises not only to be of high scientific interest, but it would undoubtedly also be a great help to those presently engaged there in explorations.

If the honorable Board of the Survey should approve these my humble suggestions, I will be ready to go to the field in the fore part of May, but if any other field work for the geologist should be preferred by the honorable Board of the Survey, he is very willing to receive the necessary orders and act in accordance with them.

Very respectfully
Your obedient servant,
[Signed] C. ROMINGER,
State Geologist.

REPORT

OF THE

STATE GEOLOGIST

FOR

1882—1883.

BY CARL ROMINGER.

EXHIBIT E.

To the Honorable Board of the Geological Survey of Michigan:

In accordance with the orders given me the previous year, I spent the greater part of the past summer season with the examination of the iron range in the Lake Agogebik district where recently a great many explorations have been going on and in part were crowned with success. The rest of my time was devoted to examination of the Iron Mining districts of Marquette and Menominee country, in which also considerable new discoveries are added to the old ones, to follow which is not only demanded for scientific reasons, but is also occasionally very important, as the evidence which the geologist can give to the explorers greatly helps their achievement of success, or on the other hand cautions them from useless and expensive operations.

During the winter my time was devoted to a careful study of the rock specimens collected in the summer. A good many chemical analyses of iron ores were made by me, and several hundred rock specimens were cut into thin sheets and mounted on glass for examination under the microscope, which is a hard, time-robbing work, but is, according to the present state of the science of lithology, indispensable.

The description of all the results obtained comprises the space of about fifty or sixty printed pages, too small for a separate publication in book form. I respectfully suggest, therefore, to wait with it until the results of another year's work can be added and a volume can be printed corresponding with the previous four volumes. The objection that it would be important for those interested in mining enterprises to have their results published as early as possible, loses some of its urgency if I say that most of these results have been in *loco*, verbally communicated already to those interested, and that I always have promptly answered any inquiries by letter and will do so with pleasure in the future.

If the honorable Board of the Survey is disposed to accept my services for the future, I should propose to spend most of my time next summer season with the examination of the Copper district, as the Iron district and the current discoveries in it can be at the same time attentively observed without interruption and with comparatively little of my time devoted to it, while in the Copper region for almost ten years nothing has been done by the Survey and justly deserves to be now the principal object of the study and work of the Survey.

Yours very respectfully,

[Signed] C. ROMINGER.

REPORT

OF THE

STATE GEOLOGIST,

FROM

MAY 1, 1885, TO JANUARY 1, 1888.

BY CHARLES E. WRIGHT.

EXHIBIT F.

To the Honorable the Board of Geological Survey, Lansing, Michigan.

GENTLEMEN—In compliance with the request of your honorable body, I herewith present a condensed statement from the monthly vouchers rendered of the expenditures incurred by the Geological Survey, beginning with May, 1886, and ending December 21, 1887; also a brief outline of the work accomplished, and of that proposed for the coming year. The field work of 1885 was confined chiefly to the north of town 48, and from ranges 25 to 33 inclusive: that is, the country to the north of the M. H. & O. R. R., to the lake between Marquette and L'Anse, covering over 700 square miles of unexplored lands, as this tract had not been examined by any of the previous Geological Surveys. It is a rough country and not easy of access. It has heretofore been colored on nearly all of the geological maps as Laurentian, whereas the results of our work show that nearly one-half of it is represented by the Huronian, or iron-bearing rocks. Within this area we have traced out the junction of the Huronian with the granite; also the southerly limits of the Potsdam sandstone that appear at many points along the shore of Lake Superior from Little Iron river near Big Bay to Huron Bay.

Within the Huronian area of this district occur the roofing slates of the Huron Bay slate quarries. These slates extend from the quarries easterly and southeasterly, with one short break of less than a half a mile to the falls on the Dead river in Sec. 9, T. 48, R. 26. This slate belt in places is eight miles wide. From the Holyoke mine, Sec. 2, T. 48, and R. 27, to just north of Silver lake in Sec. 4, T. 49, and R. 28, there are strong indications of an iron ore range; though from several pieces that we collected the ore evidently belongs to the same upper horizon as the Pascoe, Wetmore and Beaufort mines, and will no doubt prove to be non-Bessemer, at least such was the case with the samples we collected and analyzed.

The granite within this area has been considered in the previous Geological Surveys to belong to the so-called Laurentian, and therefore older than the Huronian, or iron-bearing series. On the other hand, however, the facts that we collected go to prove the reverse, that is, that the granite is more recent than Huronian, and therefore is not Laurentian. It is of igneous origin and has apparently by its uprising in the molten state caused the upheaval of the Huronian and largely brought about their present metamorphosed condition. The black argillaceous slates, where they come in contact with the granite, change into hard flinty-like jaspilites. This indurated zone often extends for several hundred feet away from the junction and the graywackes have under the same conditions been changed to graywacke quartizites.

We are now engaged in making a map on the scale of four inches to the township to accompany a detailed geological report of the above area. This map will embrace all the geological and topographical facts that have been observed by ourselves, and those obtained from the explorations of private parties.

In the prosecution of the survey we have been greatly aided by many outside parties kindly permitting us to copy the geology and topography of their field notes. From Mr. J. M. Longyear alone we have copied the notes of over 800,000 acres of land that he owns and represents for others; and have named and classified over 6,000 specimens of rocks that were carefully located by his surveys.

During the season of 1886, our work was mainly in the country lying between the Marquette and Menominee ranges, another unexplored region. We covered during that season about 500 square miles of territory; besides this, we did a little more detailed work in the district of the year before.

The indications now are that within this new area there are some valuable deposits of iron ore that will add very materially to the mineral wealth of the State.

During the season of 1887, just passed, we have continued the work within the same district and have the geology of the district fairly well worked out from say range 28 of the Felch mountain district to range 34, inclusive of the Iron river district. The strike of the rocks from here westward is about west northwest.

In all our work we have noted in traveling through the woods every hundred paces the magnetic dip of the dipping needle and, when the sun shone, the variation of the compass needle to the east or west. This will enable us to lay down on the maps the exact position of the magnetic belts of attraction. Some of these covered magnetic belts we have traced for 15 miles. While it is not always true that these lines of magnetic attraction emanate from belts of merchantable iron ore, they still possess great value by indicating, in most cases, the strike or trend of the covered rocks.

It is my present plan to continue this work westward from range 34 and cover the Huronian or iron-bearing series in the same systematic manner as has been done to the east.

The country westward to Gogebic lake is probably mostly flat and deeply covered with drift. If such be the case, we shall be well into the Gogebic district proper before the close of this season.

The advantage of working in this systematic way is that the facts obtained from day to day greatly assist in the advancement of the work. There is constantly more or less detail work that has to be performed after the specimens have been determined and classified in the office; but this we have endeavored to keep as close in hand to the other work as is possible.

The office work proper requires the making of thin sections of nearly all the specimens we collect; then follows a description and classification of the same. The older methods of determining rocks alone by their appearance and analysis is no longer depended upon by the modern geologists, for the reason that results are unreliable and therefore misleading.

GAS AND SALT WELLS.

In addition to the work done in the Lake Superior district I began, in 1885, to collect the records of the deep wells that had been sunk for salt. With the wells that were then being sunk I arranged, as far as was possible, to have samples of the drillings of the different strata passed through saved in small bottles, furnished by the Geological Survey. This has been continued till the present time, and is in fact still in operation. For the past year I have been able to furnish parties who contemplated sinking a gas or salt well, with a geological diagram of some locality nearest them, where a well had been sunk, showing the different strata and their geological equivalents. That you may form an idea of what is meant by the above, I will enclose diagrams of a number of gas wells sunk in different parts of the lower peninsula. The practical advantages of these diagrams are that they enable the parties to compare the results of their own drilling, from day to day, and to form an intelligent idea of about where they are geologically. Whether they have reached the same horizon where gas was obtained elsewhere, etc. In addition to the practical side, it affords geologically one of the finest possible cross sections, and, when taken one with another, a fair idea of the structure of the rocks underlying large areas. I shall endeavor the coming season to get parties interested in the boring for gas in the upper peninsula between say Escanaba and St. Ignace, and in the region south of the Duluth, South Shore & Atlantic Railway. The prospects for gas within this territory are certainly very good. As far as I can judge, the geological conditions are very favorable. The Trenton limestone, the gas horizon of the Findlay district of Ohio, has a good cover of argillaceous shales here, to prevent the escape of the gas. The shales undoubtedly overlying are somewhat bituminous, and the Trenton is in places of a porous character. The formation has a very slight dip to the south, and is probably undulating, and therefore in places arched, one of the conditions for a natural gas supply. None of the holes, I believe, will need be more 1,500 feet deep to reach the Trenton rock, and the most of them very much less. Trusting that the above brief outline may prove satisfactory, I remain,

Yours respectfully,
CHAS. E. WRIGHT.

Presented, January, 1888.
Receipt acknowledge, January 25, 1888.

REPORT

OF THE

STATE GEOLOGIST

FOR

1888—1889.

BY M. E WADSWORTH.

EXHIBIT G.

REPORT OF THE STATE GEOLOGIST FOR 1888-1889.

To the Honorable Board of the State Geological Survey of Michigan:

GENTLEMEN—The death of the lamented late State Geologist and my intimate friend Charles E. Wright, M. E., has inflicted an irreparable loss on the Michigan Geological Survey. While he had planned and laid out the work on a broad scale, he had delayed putting his part of the work and his conclusions into writing, except in a very minor degree. He had intended to do this during the years 1888 and 1889. Being by nature cautious, he endeavored to look over every part of the field before he committed himself to writing. After his work was grasped in all its details it was usual for him to put it into shape and into manuscript with great rapidity. Unfortunately for the State, he gave himself no rest, but worked on and on, until his vital force was exhausted, and so far as his work was concerned, was taken out of it as suddenly and unprepared as if he had been struck down on a battle field. While the above statement is true concerning his own manuscript, yet the organization of the Survey remained, all the maps, field-notes, specimens and sections; but in an undigested form. That work had been done by him, but not having been committed to paper, it was all taken with him to our great loss and sorrow.

In entering upon my work I have had, to aid me, my previous work on the region, and my familiarity with the literature of the work done in this and other regions of similar character. Further, Mr. Wright and myself were in general accord in our views, concerning the rocks of Northern Michigan. He had spent many weeks with me in Maine in 1885-86 working over these rocks and their problems, and since I have been in Michigan, until his death, we held frequent and long consultations over various problems that had arisen in his work. His conclusions and results were not in accord with those obtained by the United States Survey at that time, and all representations of that kind made to the Board are erroneous. I have further for my aid the former members of his survey corps, and all the notes, maps, specimens and sections which he and they had prepared. But I must do as he had done, digest it all—a labor of vast proportions. Meanwhile I have endeavored to keep the Survey work moving steadily onwards, as had been done under Mr. Wright's direction, making only such modifications as experience might dictate.

During the season of 1888 the geological field work was taken up in T. 43 N., R. 35 W. This point was selected on account of the field work having, in a large measure, been completed westerly from Marquette to a line drawn from Iron river village (Sec. 26, T. 43, R. 35 W.) northwardly to the south end of Keweenaw Bay near L'Anse. The field work during the season of 1888 covered the ground that lies between Iron river and Lake Gogebic on the west and from the State Boundary to Township 46 on the North. The region covered last season contained comparatively few outcrops, and was a somewhat difficult area to explore. The rocks are mainly interstratified argillites and sandstones, which are frequently cut by dikes of melaphyr, diabase and diorite. In the western portion granites occur, while the sedimentary rocks are more highly indurated, and contain much mica, chlorite, and hornblende. Owing to metamorphic action and the development of a schistose structure, it is with extreme difficulty that the bedding planes can be determined, while in many cases it is impossible to discover them.

The clevage when developed is always at a high angle, but the bedding planes were seldom found at a greater angle than 45°, and generally at a much less angle. The dips are either to the North or to the South. Within this area there are some belts of slight magnetic attraction, as at the south of Sec. 20, T. 44 N., R. 36 W.; also in the northern portions of Secs. 16, 17 and 18 of T. 43 N., R. 37 W. Magnetic attractions of a slight and local character were noticed at points further west.

On Sec. 8, T. 44 N., R. 35 W. some exploring pits had been sunk to an iron ore. The formation here appears to trend southwesterly, as a rock apparently of the same character as that capping the ore appears on the surface near the S. E. corner of Sec. 14, T. 44 N., R. 36 W. Test pits had been sunk, with discouraging results, on Sec. 28, T. 44 N., R. 36 W. in rocks that were dark argillites with argillaceous sandstones.

The timber resources of the country explored last season remain much the same as they were when the linear survey of the United States Land Office was made. Although there have been some devastating forest fires in this region, there seems to have been but little valuable timber destroyed. For the past two years, the lumbering interests in the district have been quite extensive, yet but comparatively little of the pine has been cut.

The work not completed under the direction of Mr. Wright east of the line running from Iron river village to the head of Keweenaw bay is mainly as follows: Detail work in the Iron Regions, as at Norway in the Menominee Range, near the Metropolitan on the Felch Mountain Range and near Ishpeming and Negaunee along the Marquette Range, and in the Gold District. In addition to the adjacent field work, the iron mines need, in the light of their present developments, further examination. There is need of further work northward towards Huron Bay, while at the northwest of Marquette there is quite an area of unexplored territory. Other unsurveyed areas are four or five townships between Ford River and Ishpeming; T. 45, R. 34 W. is a portion left, owing to the wetness of the season when that region was explored. During the past season considerable work has been done in bringing up the details mentioned, and in settling problems that Mr. Wright himself had intended to take up again. This work was done by the State Geologist and his first assistant, Mr. A. E. Seaman. The region studied was in the vicinity of Marquette, and along the lake shore northward as well as in the vicinity of Ishpeming. Detailed work was done along the shore and on the adjacent islands to the north of Marquette, while maps showing the geology on a large scale were drawn. A cross section was nearly completed from Granite Point (Little

Presque Isle) to the granite south of Carp River or about one mile south of the Northern State Prison. A cross section was begun near Ishpeming but was not finished owing to the stormy weather, which greatly impeded and shortened the work last season.

There have been thus far about seventy townships explored and their geology mapped with sufficient accuracy so that maps of the townships might be published as preliminary maps, and serve as a great aid to explorers. Much of the time of the State Geologist has been taken up by the executive and office work, in answering various scientific and economic questions put to him by the citizens of the State; and in the southern part of the State in questions concerning gas wells. The general office work of the Survey has been kept well in hand, maps made, and the results of the field explorations mapped out.

One important problem in the Copper District deserves immediate attention: Do the Copper-bearing rocks end at their junction with the Eastern sandstone, or do they continue under that sandstone and may we hope by explorations with the diamond drill or otherwise greatly to extend our resources in that direction?

Some work on that problem was done during the last season, until stopped by the severe rains. It is proposed to continue this work during the coming season, and endeavor to settle the question beyond controversy or else demonstrate that, with our present means, its solution is impracticable. It is further proposed to continue the survey westward along the line taken last season until the western limits of the State are reached. So far as time permits, the problems and unexplored districts mentioned as occurring in the regions covered by Mr. Wright will be taken up. The petrographical study of the rocks collected in the Survey has been continued and will be pushed to completion. In the line of publication the authority and advice of the Board is desired. As mentioned before, it is suggested that the township maps be published as completed, either for distribution, or for sale at a moderate price. the latter course being generally the most satisfactory in the prevention of waste and in placing the maps in the hands of the parties who most need them. Preparation should be made for the engraving or lithographing the plates and maps of the geological and petrographical reports of the Survey; and that work should be commenced shortly, for until that is done no attempt at publication can be commenced.

The State Geologist would suggest as a tentative plan for the future work of the Survey that after the work already outlined be completed, the Copper District be taken up. including Isle' Royale and its adjacent islands. Subsequently the Survey should be extended eastward, until all the Upper Peninsula has been surveyed, and then southward over the entire Southern Peninsula. Of course. any sufficient cause could change the plan.

It has not seemed wise to the State Geologist to fritter away his time by running hither and thither to pursue the reports of newspapers and speculators; therefore he has not followed out the reports on the Gold Fields of Michigan. In his legitimate work he visited the Ropes Mine and found it to be on a segregated vein and not on a fissure vein, as had been reported; while from the samples seen and from the general reports there would appear to be but little doubt that the other gold finds are upon similar veins. Success in working such veins demands an entirely different method from that employed in working true fissure veins.

It is further suggested that the Board authorize the publication of the sections and results obtained from the salt and gas well borings.

The chief function of the Geological Survey and the State Geologist is to prevent the rash and foolish expenditure of money in undertakings that of themselves are hopeless; also in cases, that have proper grounds to support them, to direct the work, where geologically there is the greatest hope of success. Besides giving correct information in many cases where people have mistaken worthless materials for valuable substances, he has the pleasure of feeling that he has saved the people of Bellevue from five to ten thousand dollars, which would have been spent in useless drilling for gas under a mistaken idea of the geological structure of their township.

It is not too much to say that the citizens of Michigan might have been saved hundreds of thousands of dollars, now wasted in explorations for natural gas, had they availed themselves of the information they might have had for the mere asking. But many years ago the State Geologist learned not to proffer unsought advice.

During the administration of Mr. Wright, and subsequently in my own, collections have been made to distribute to the different schools as required by law, which distribution, it is hoped, will be made during the coming spring.

Very respectfully,

February 26, 1889. M. E. WADSWORTH.

REPORT

OF THE

STATE GEOLOGIST

FOR

1889—1890.

BY M. E. WADSWORTH.

4

EXHIBIT H.

REPORT, 1889-1890.

March 1. 1890.

To the Honorable Board of the Geological Survey of the State of Michigan. Lansing, Michigan:

GENTLEMEN—It is intended for the present Reports of the Geological Survey of Michigan to cover approximately the following points:

1. Introduction.
2. The republications of the reports of Dr. Douglass Houghton, the first State Geologist of this State; provided your honorable Board gives its consent to the same. These reports are out of print and only a very few copies known. I think that the republication is something that will be appreciated both by the citizens of this State and by geologists the world over.
3. Rominger's report.
4. Sketch of the life of Charles E. Wright, M. E., late State Geologist.
5. Mr. Wright's annual report.
6. Account of the borings for gas and salt in Michigan, the sections of strata passed through, and a discussion of the question of natural gas.
7. Maps of the surface distribution of the rocks in Northern Michigan, for the use of explorers, woodsmen, prospectors, and others, about 100 townships. The cost would be approximately about $9 to $12 per map, exclusive of presswork and paper. These maps could be published separately for sale if desired.
8. A description of the rocks and ores collected and mapped by the Survey, including their classification and relations, illustrated by maps. lithographs, etc.
9. The rectification of the boundary between the Copper-bearing rocks and the Eastern sandstone, and a discussion of the relations of both.
10. Special work done in the general and economic geology of the State.

The more general economic geology of the State will be left to appear in later volumes, or else a delay will have to take place in the publication of part, at least. of the work done at present, as laid out by Mr. Wright. The proposed plan for the future work of the State Geologist and his assistants will be to study the economic geology of the building stones, salt, coal, iron, copper, gypsum, lime, fertilizers, gold, etc., of the State, looking to their development. In addition work will be continued upon the surface distribution of the rocks. As the State Geologist has before written to His Excellency, the Governor, he is willing to undertake during the present summer to work up as far as possible the economic geology of the deposits before referred to, should your honorable Board judge that the best interests of the State demanded that this work should be done previously to the full publication of the past work of the Survey.

During the past season one party was sent into the field to finish the mapping of the area west of the Gogebic Lake and south of the copper bearing rocks and the sandstone, through to the State line, south and west. This work was completed and a formerly unexplored township, No. 45, range 34, was also surveyed, and the magnetic belt traced. Another party, under the more direct supervision of the State Geologist, was sent to rectify the published boundary of the copper bearing rocks with the eastern sandstone, between Bête Gris Bay and southwesterly to Gogebic Lake. Excavations were made and careful surveys undertaken to ascertain the exact relations of the two formations, it being considered a matter of much economic importance. The office work of course has been continued, with the mapping of the results of the field work. Further, Dr. A. C. Lane has been employed for the greater part of his time in the microscopic study of the rocks collected by the Survey, and in writing out descriptions of the same. The specimens of the Survey are arranged and distributed in drawers provided by the Michigan Mining School. All have been properly labeled. The Survey has now a collection of about 5,300 specimens of rocks and minerals, with about the same number of microscopic sections. Chemical analyses are now being made of some of the building stones of the State, together with tests of their resistance to crushing. The work of the collection and description of specimens to be distributed to the colleges of the State is still continued. A distribution it is hoped will take place in the spring. It was intended to send them out last spring or during the winter holidays, but unforeseen events prevented.

Through the personal influence of the State Geologist and his assistants, sufficient attention has been called to the granite of Northern Michigan to lead parties to commence making arrangements to quarry the same. If that industry can be started, the increase of the wealth of Michigan will be far more than the expense of twenty such geological surveys as we have at present. The State Geologist has had, as usual, much work to do answering letters asking for information, and in examining specimens sent to him, as well as in the examination of various economic questions that have been brought to his notice. Information and advice have always been freely given whenever asked, and it is always his effort to prevent waste of money in useless work, on the part of citizens of the State.

The Michigan Mining School now provides the State Geological Survey with room, cases for collections, heat and light, use of libraries, etc., etc., rent free, on condition that certain assistance may be rendered the School by the employés of the Survey, when needed, and when it shall not interfere with their professional duties on the State Survey. In fact, it has been arranged that an interchange of assistance shall be rendered between the two institutions. The object of this is to save, on the part of each organization, a duplication of officers; as this gives skilled help in one or the other organization as may be needed, without being obliged either to go outside, or to engage the entire time of some person, or do the work under great disadvantages. It is intended to keep the assistance rendered on both sides balanced, either by the interchange of labor or by the payment by one party for the services of the other. This results in a large saving to the State, and in no loss, but rather in a great gain to each institution.

An arrangement has been made with the United States Geological Survey, for coöperation on the part of both Surveys in their work in the State of Michigan, in order to save duplication. This arrangement will result in mutual benefit both to the State Geological Survey and to the United States Geological Survey. Copies of the correspondence are presented to you for your approval; and should you approve such arrangement it will go into effect. I also ask that the honorable Board of the Geological Survey shall request his excellency, the Governor, to write to the Superintendent of the United States Coast and Geodetic Survey, Prof. T. C. Mendenhall, asking him to undertake, in coöperation with the State Geological Survey of Michigan, the triangulation of the State, the making of a topographical map, and the running of a line of levels in the State of Michigan, so far as may be done in accordance with the laws of the United States. This work will be done without expense to the State, and it is believed will be of great advantage to it. It can, however, only be entered upon by request of the Governor.

Any further information that may be desired by your honorable Board in reference to the work of the Survey, or the plans of the same, will be freely furnished. On the other hand, your honorable Board is requested to inform the State Geologist in what way and manner the report is to be printed. By whom are the maps, lithographs, etc., to be paid, *i. e.*, by the State Geological Survey or by a general fund of the State, or by a special appropriation? Is the report to be presented in manuscript, with manuscript maps, etc., or is it to be presented in printed form to you?

Yours very respectfully,
M. E. WADSWORTH,
State Geologist.

[Dictated. R. I. R.]

REPORT

OF THE

STATE GEOLOGIST,

FOR

1890—1891.

BY M. E. WADSWORTH.

EXHIBIT I.

To the Honorable Board of the Geological Survey of the State of Michigan:

Gentlemen—In response to the request of His Excellency, the Governor of the State of Michigan, I have to present to you the following statement concerning the past, present and proposed work of the Geological Survey of Michigan:

The last report on behalf of the Geological Survey was issued in 1881, covering the work up to that year, by Dr. C. Rominger then State Geologist. A later report was presented by Dr. Rominger in 1885 for the years 1881–1884, which has not been published, but which it is proposed to publish with the other work of the Survey. In 1885 Charles E. Wright. M. E., was appointed State Geologist, vice Dr. Rominger, resigned. Mr. Wright took up the work with earnestness and vigor, giving to it all the time he could spare from his extensive private business, and bringing to the Survey his practical knowledge of the various iron ore formations of the State.

During the year 1885 the field work was confined chiefly to the north of town 48, from ranges 25 to 33 inclusive, covering some 700 square miles. In 1886 the work was mainly in the country lying between the Marquette and Menominee ranges. In 1887 the work was continued in the same region. In addition, collections of the borings from the salt and gas wells were made and sections drawn showing the different strata through which the wells passed. Microscopic sections of the specimens of the rocks collected by the Survey were made, and studied to some extent. while the outcrops were marked on the township maps. At this stage of the work and before a single page of his report was written, Mr. Wright died after a brief illness.

On account of the present writer's intimate personal relations with Mr. Wright, his knowledge of the latter's views and work and also on account of his former studies in the petrography and geology of the region, he was appointed State Geologist.

During the season of 1888, the previously formed plans of Mr. Wright were carried out and the same assistants employed as far as possible. The field-work in 1888 covered the ground between Iron River and Gogebic Lake and between the State boundary and township 46 on the north. Further work was done in the Marquette district in mapping unsurveyed areas and in the study of special problems.

In 1889 the work was pushed westward from Gogebic Lake to the western boundary of the State, and the eastern boundary of the copper bearing rocks was explored.

In 1890 the Gold district was studied, sections made, and material collected for a full report, while numerous specimens were collected for the colleges. Special work was also done in the Marquette Iron District, in exploring new ground and in endeavoring to solve special problems concerning the origin and relations of the iron ores; as upon their correct solution depends the future of Michigan's iron industry.

In accordance with the law, Mr. Wright had begun to make collections for distribution to the incorporated colleges of the State. This collecting, as already stated, has been continued by the present State Geologist, and the specimens were distributed in December, 1890.

The execution of this law greatly interferes with the proper field and office work of the Survey and the results are as nothing compared with the attendant expenses to the State.

It had been intended to make the distribution in 1889, but unforeseen difficulties prevented.

One of the greatest difficulties that the Survey has to contend with on every side, is that the appropriation given it is so very small compared with the results the Survey is expected by law to accomplish, that no one thing can be carried to completion before it is interfered with by demands for something else.

Since the present State Geologist took charge of the Survey work, he has been endeavoring to carry on the field work and at the same time to bring up the office work to a point at which publication could begin. It has thus far been impossible to publish, for the work carried on had to be commenced in the middle, and no proper publication can begin until at least the correct basis of the whole is obtained. It needs to be remembered that the region in which the Survey has been working is one of the most difficult geological districts known, and hardly a single thing can be predicated one inch beyond the parts seen. This requires extreme care and oftentimes a re-study of the same ground many times.

Notwithstanding all efforts, the office work is much behind the field-work; so much so that if the attention of the Survey is confined exclusively to the regions studied under the direction of Mr. Wright and of myself, and it does only such field-work as is now needed to clear up certain points in those regions upon which the data at present obtained are too imperfect, it will take at the very least three years from next May to have the office work all completed and prepared for publication.

It is, however, not wise to fix an arbitrary date on which the work must be ready, since such a method leads to crude and imperfect reports.

During the coming summer it is intended to study only certain points which must be studied in the field in order to complete the preceding work for publication.

It has been found necessary to go over much of the preceding field work, in order to utilize the sketches, figures, etc., of Mr. Wright and his assistants. This was because the work was not written out in sufficient detail to allow a report to be made, except by the person that made the previous examination, or until the exact meaning of the figures and the relations of the rocks were obtained by a personal re-examination of the points in question. So many and so very difficult points had been brought up by Mr. Wright's work and by the subsequent field work that thus far it has been impossible to get the material ready for the press.

The State Geologist's work is now brought to a point where its preparation for publication can be completed, if given sufficient time. Any suspension of its operations or any change in the Survey now would result either in putting back the publication for many years, or more probably would cause the entire loss to the State of the past ten years' work already done, since no one can take up the work of another, in its partial development, and carry it on as fully and rapidly as the originator himself. The past has plainly shown the delays and losses consequent upon changing one State Geologist and upon the death of the other. As a rule, the most valuable portions of any geologist's work are the results of long continued study and experience and in every case they will remain unwritten until the final draft of the report is prepared; it was so with Mr. Wright's report; it is so with the present State Geologist's reports.

The work personally done by the State Geologist on the Survey covers the same ground that his work as an instructor in the Mining School covers, as can be seen by the subjects already worked out to a greater or less extent by himself and his assistants, in preparation for publication in the reports of the Geological Survey.

1st. History of the former geological work done in Michigan, with the results obtained.

2d. A general index to all past publications that relate to the general and economic geology of Michigan, giving ranges, townships and sections, as an aid to the explorer, miner, quarryman and others.

3d. Republication of the reports of Dr. Douglass Houghton.

4th. Unpublished report of Dr. Carl Rominger.

5th. Sketch of the life of Charles E. Wright, M. E., late State Geologist, containing his Annual Report.

6th. Township or district maps of the distribution of the rocks and geological formations, for the use of the explorer and others, covering the chief part of the counties of Baraga, Marquette, Iron, Menominee, and Gogebic, with some portions of Ontonagon, Houghton, and Keweenaw counties.

7th. Descriptive text to accompany the above maps containing an account of the geological structure so far as known, and a description of the observed rocks and minerals. About 5,000 manuscript pages of this part of the work have been prepared.

8th. A classification and description of the minerals of Michigan, their distribution, methods of determination, etc., to assist the explorer and others.

9th. A general classification and description of rocks, with special relation to Michigan rocks, for general use.

10th. A general classification and description of ore deposits in general, with special reference to the Michigan ore deposits, as an assistance to explorers, miners and others.

11th. The iron ore deposits of Michigan, their origin and relations, with sections, maps, etc., together with a discussion of the comparative relations of other iron ore deposits.

12th. The gold and silver deposits of Michigan, with maps, etc., together with a comparison of the mode of occurrence of related deposits.

13th. The copper deposits of Michigan and related districts.

14th. The gas and salt wells of Michigan, with sections and a general discussion of the occurrence of gas, petroleum and salt.

15th. The building stones, their properties, mode of occurrence, etc.

16th. Gypsum, coal. limes, clays, marls, and the minor mineral products of Michigan.

17th. Methods of mining, timbering, hoisting, etc., particularly those employed in Michigan.

18th. Methods of ore dressing used in Michigan. and elsewhere if adapted to Michigan products.

19th. Metallurgical processes suitable for use in Michigan.

20th. Rectification of the boundary line between the copper bearing rocks and the Eastern sandstone, with a discussion of their relations, and of the probable extension of the copper belt.

It will be seen from the preceding pages that the Survey has been and is endeavoring to do all that its limited and very small means will allow to aid in the development of the resources of the State; also, that its work is in direct connection with the work in the only institution in the State that has been organized to train men to assist in that development. The inquiries constantly received by the State Geologist show him that points taken up in the above reports are the ones upon which information is most sought for as an aid in developing the mineral resources of the State. By a combination of the resources of both the Mining School and Survey, and by their union in common work, each organization gains greatly in strength—one in its ability, knowledge and men, thus enabling it to give better instruction; the other in means, men, laboratories, library and knowledge, to enable it to do practical work better; and that which is above all, the State, as a whole, receives far more for the same expenditure than it could if both organizations were separated.

The Geological Survey has now a complete organization, such as it never before had, an organization that was completed only with great difficulty, and after nearly three years of trial. It has now an able and efficient corps of assistants, and is prepared to take a rank, proportionate to its means, among State Geological Surveys. Shall the labor of organizing this corps be rendered in vain?

Arrangements have been made with the United States Geological Survey and the United States Coast Survey for harmonious coöperation in our respective labors. This enables the Michigan Survey to give most of its time to the work necessary to be done in connection with the economic geology of the State, leaving the more purely scientific aspects to the United States Survey, particularly the palæontological work. Plans are being formulated for a complete topographical map of Michigan, in part at least by the aid of the United States Coast Survey and the United States Geological Survey.

After the work above outlined is completed, work upon the soils, distribution of timber and numerous other subjects will be taken up as soon as possible.

It is believed to be better to have the work of the Survey in detached parts rather than in the large volumes which have previously been issued. However this may be, the State Geologist sees no reason why the publication of parts of the reports should not begin next year, unless the want of sufficient means should prevent the accomplishment of necessary work in the meantime.

Much of the time of the State Geologist is taken up in answering questions on points of economic interest to citizens of the State, and oftentimes in dissuading them from engaging in wild schemes.

Information and aid are sought from all over the State, and all that can justly be given is freely given to each inquirer. This information seems to be sought very largely by persons not actively engaged in mining work —that is, by the masses who have not at hand the means of otherwise obtaining the information sought.

The State Geologist believes that, if the present work and plans are continued as now laid out, within a few years the Survey will be a pride and credit to the State, as well as a great aid in the development of its vast mineral resources—which is the end for which it was organized, and the end which the present State Geologist is steadily endeavoring to reach.

Very respectfully,

[Signed] M. E. WADSWORTH.

Houghton, March 17, 1891.

REPORT

OF THE

STATE GEOLOGIST

FOR

1891—1892.

BY M. E WADSWORTH.

EXHIBIT J.

To the Honorable, the Board of the Geological Survey of Michigan:

GENTLEMEN—This, the annual report of the State Geologist for 1891–1892 was completed under date of February 29, 1892, and forwarded to you. In accordance with a special request, on the part of your committee, it gave much space to the past work of the Survey and to other matters that I already touched upon in previous reports, which reports are now about to be published. In view of these facts your committee last week preferred that such portions of it as related to the above topics be omitted and that it be revised so as to include as much of the work of 1892 as practicable. In compliance with that request this report has been it part rewritten.

For publication with the report of February 29, the following papers were transmitted:

A. Statement of the expenditures at the office of the State Geologist from May 1, 1885, to January 1, 1888.
BY CHARLES E. WRIGHT.

B. Statement of the expenditures at the office of the State Geologist from May 1, 1888, to January 1, 1892.
BY M. E. WADSWORTH.

C. General expenditures of the Geological Survey from 1837 to 1845, from 1859 to 1862, and from 1870 to July, 1891.
FROM THE STATE AUDITOR'S OFFICE.

D. Report of the State Geologist for 1881–1882.
BY CARL ROMINGER.

E. Report of the State Geologist for 1882–1883.
BY CARL ROMINGER.

F. Report of the State Geologist from May 1, 1885, to January 1, 1888.
BY CHARLES E. WRIGHT.

G. Report of the State Geologist for 1888–1889.
BY M. E. WADSWORTH.

H. Report of the State Geologist for 1889–1890.
BY M. E. WADSWORTH.

I. Report of the State Geologist for 1890–1891.

BY M. E. WADSWORTH.

J. *A sketch of the Geology of the Iron, Gold and Copper Districts of Michigan.

BY M. E. WADSWORTH.

K. †Report upon the Geology of Michigan, 1881–1884.

BY CARL ROMINGER.

To the report marked J. there are appended three reports made to myself by the assistants, upon the results obtained by them in certain special lines of work to which they were assigned.

Schedule B gives a condensed account of the expenditures of the Survey at the State Geologist's office from May 1, 1888, to Jan. 1, 1892. The itemized vouchers for these expenditures are on file at the Executive Clerk's office and at the office of the State Auditor, where they can be readily examined for any special details.

Nearly all of these papers had been presented previously to your honorable Board, but had not been published.

Since the date of my report for 1890–1891 the office work has been continued, except when interrupted by the field-work.

This field-work began June, 1891, at Champion and in the adjacent region, and extended south of Clarksburg to Palmer and the vicinity of Negaunee.

Later a party was sent into the Huron Mountain district, to traverse the line of the Huron Bay railroad. Through the chief portion of this region gneiss appeared to be the predominating rock. Another party was sent to the limestone region in the vicinity of L'Anse, to determine the relation of the limestone there to the Eastern sandstone. Parties were then dispatched to follow the South Trap Range from Silver Mountain through to Lake Gogebic, and beyond. In continuation of this work, the Gogebic Range was studied to a greater or less extent from Wakefield to Ironwood. While there the party made some observations concerning the relation of the South Trap Range to the iron-bearing rocks, and to some associate dikes. In the effort to connect the former observations, and to trace out the junction of these rocks with the Eastern Sandstone as far westward as possible, the work was also continued east and west of the northern end of Lake Gogebic. During this time, and later, a party was engaged in working in the Menominee and Marquette Iron Regions, particularly in the former, about Crystal Falls, Iron Mountain, Quinnesec, Norway, Felch Mountain, etc.

As far as was practicable the office work was continued during the summer, and since the field work has closed the former has been vigorously prosecuted. The office work consists in making thin sections of the rocks collected, their microscopic study, cataloguing and writing descriptions of the same, mapping the outcrops and formations, and preparing the manuscript, plates, etc., for the report. It is essential that a large amount of this work be done before the final arrangement for publication can take place, and it is especially necessary that the work of the assistants should be completed before the general discussion of the work can be made with sufficient accuracy by the State Geologist.

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*See Exhibit K, this report.—(S. S. B.)

†Not published here, see page 4.—(S. S. B.)

For purposes of study and mapping, the ground already traversed by the Survey has been roughly divided into five districts:

1st. The Marquette District, including the Gold Range and the Huron Mountain Region.

2d. The Menominee District.

3d. The Ontonagon River District.

4th. The Gogebic District.

5th. The Keweenaw District.

During the season of 1892, field work has been carried on in various localities by Messrs. Seaman and Lane and by the State Geologist.

South of the Winthrop Mine, on section 28, the conglomeratic base of the Republic formation was found resting on the old gneisses and granites of the Cascade formation. The quartzite on Secs. 33 and 34, T. 48, R. 27, north of Ishpeming and west of Teal Lake, was found to rest, with a thinly bedded conglomeratic base, on the older chloritic and sericitic schists that form the surface rocks to the north. These schists are traversed by numerous dikes and in general resemble some of the schists of the Republic formation. The basement conglomerate of the quartzite contains fragments of jaspilite, hematite, quartz. and schist, and evidently belongs to the Holyoke formation. The conglomerate east of Teal Lake was found to be of a similar character. One of the facts of great interest, brought out by the field-work of the Survey during the past summer, is the separation of the quartzite that underlies the dolomitic series from that which overlies it.

Beginning in the northeast corner of Sec. 1, T. 47, R. 25, the quartzite was found in a synclinal position. Following the south side of the synclinal west, the quartzite was seen to extend in a rather uniform direction to the east $\frac{1}{4}$ S.* of Sec. 8, T. 47. R. 25, at which point it bends abruptly south, and can be traced to the southeast corner of the section. It then bends more easterly on section 16, and is finally lost beneath the heavy drift covered plains to the south. It is next seen near the southwest corner of section 17, and can be traced west to Sec. 21, T. 47. R. 26. In its southward course the quartzite, which is here conglomeratic, flanks the granite and gneiss area, and is made up principally of their debris. Many pebbles of quartz occur and in places the conglomerate is strewn with rounded or slightly angular fragments of hematite and jaspilite. Above this quartzite, and seemingly conformable with it, is a thick series of alternating dolomites and calcareous argillites, which series is quite arenaceous in the upper portion.

These dolomites and argillites form the chief surface rocks on Secs. 8 and 17, where they dip west or northwesterly at about 30 degrees, and are well developed on the east half of Sec. 5, T. 47, R. 25. In the center of section 5 heavy beds of quartzite occur. About 400 paces west of the north $\frac{1}{4}$ S. of section 5, we find the quartzite dipping southwesterly. The lowest exposed strata are thinly bedded, and resemble the finely banded quartz schist at the base of the Teal Lake quartzite, exposed on Sec. 33, T. 48, R. 27. Below the quartz schist is a red slate, but no contact of the two was seen. Higher up in the series the quartzite becomes quite massive. To the west, on Sec. 31, T. 48, R. 25, about 450 paces west of the S. E. corner, the quartzite is exposed in a trench that crosses the formation. The highest exposed strata are massive

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[*] $\frac{1}{4}$ S. is a convenient abbreviation for the quarter post or stake and is much used by explorers and others in Michigan.

quartzite; below this comes the thinly bedded quartz schist already mentioned as occurring on Sec. 5, T. 47, R. 25. This schist passes downward into a conglomerate that holds fragments of slate, quartz, chert, etc. Below this conglomerate is a chert, that seems to have furnished the material from which the conglomerate was formed. This then would indicate that the quartzite unconformably overlies the black and red slate series. The quartzite was traced westward to near the center of Sec. 36, T. 48, R. 26, at which point it was lost under heavy drift accumulations. The Teal Lake quartzite is probably the westward continuation of this series.

If from the north ¼S. of Sec. 5, T. 47, R. 25 the outcrop of quartzite is traced southerly, it will be found that near the center of the section it swings abruptly to the west, and has an inclination of about 30 degrees to the north. The black slates that underlie the quartzite can be traced in the valley, and are largely exposed in the river on the S. W. ¼ of the section. The quartzite can be traced west to near the center of the S. E. ¼ of Sec. 6, where it can again be seen in unconformable juxtaposition with the black slates. Here, as on Sec. 31, T. 48, R. 25, the lower portion is conglomeratic and passes upward into a thinly bedded quartz schist, that gradually assumes a more massive state, until fifty feet above the contact the bedding is scarcely perceptible. Not far from here the quartzite and an overhanging slate and graywacke are brought into an unconformable position by faulting. The upturned edges of the slate show that they are on the downthrow side. The strike of the quartzite here is a little west of south, and if it is followed it will be seen that near the center of Sec. 7. this rock comes very much nearer to the dolomite than it did in Sec. 5. This is due to the fact that it appears to have overlapped the slate. The quartzite bends west on Sec. 7, and can be traced across Sec. 12, T. 47, R. 26, and into Sec. 11. where it takes a more decidedly southwesterly course, and about 400 paces west of the south ¼S., crosses the south line of Sec. 11 into the N. W. ¼ of Sec. 14, where it outcrops again along the shore of Goose Lake. It is lost under the water of the lake only to appear in the opposite bank of the N. W. arm of the lake, where it is well exposed in a railroad cut, and in an old quarry near by. It extends across the southeast part of section 15, and is well exposed at the south ¼S., where it dips under the drift at an angle of 28 degrees N. From the east ¼S., it extends southwest, and strikes into another quartzite that forms a high chain of hills through Secs. 23, 22 and 21. This last mentioned quartzite is considered as the westward continuation of the quartzite forming the synclinal exposed on Sec. 1, T. 47, R. 25.

The upper quartzite west from the south ¼S. of Sec. 15, T. 47, R. 26., apparently flanks the older quartzite hills, and has about the same general strike, as far west as the S. E. ¼ of Sec. 16, at which point it begins to swing southerly again. It outcrops in a high ridge about 500 paces south of the north ¼ S. of Sec. 21, and bearing west of south can be traced towards the southwest corner of the section, for about half a mile, when it disappears in low ground near the line. It can be seen again on the N. E. ¼ of Sec. 29, and from here seems to connect with the Holyoke series that is exposed along the north and south center line of the section, and along the south line, in the direction of the Volunteer Mine.

From the foregoing it will be seen that the Mt. Mesnard quartzite and dolomitic series has been entirely crossed by the course of the Holyoke quartzite, and this offers an explanation of the fact that the dolomites are not seen west of Goose Lake. They are buried by an overlying uncomformable series.

There is one more fact worthy of note in this connection. On Sec. 29, T. 48, R. 25, a conglomerate is exposed on the north side of the old county road, a short distance north of a small lake in which the south ¼ S. of the section is located. This conglomerate holds pebbles of granite and green schist, scattered through a green matrix. Overlying this is a quartzose, or arenaceous schist. Above the schist and exposed on the north side of the lake is the Mt. Mesnard quartzite. In following this quartzite east, we find on sections 33 and 34 that it is separated from the arenaceous schist by a conglomerate. The conglomerate contains pebbles that are now hematite, also quartz and schist fragments. In studying the contact but little unconformity could be observed.

A rock with a striking lithological resemblance to this was observed on sections 21, 22, 27 and 28, T. 47, R. 26. On section 22 it seems to pass up into a granitic conglomerate that locally becomes quite sericitic. Whether this arenaceous schist and the dolomite series are one continuous formation, or not, is not yet determined.

The question now arises: Where shall the dolomite series with its quartzite be placed? Is it a part of the Republic formation or does it overlie it?

While the evidence is not yet conclusive, that which has been obtained indicates that the dolomites unconformably overlie the Republic formation. Pebbles of iron and jaspilite are abundant in the conglomerate at the base of the dolomite series. Again, the quartzite of the dolomite series does not seem to have undergone such intense dynamical metamorphism as that at the base of the Republic series, although they both have many characters in common, *e. g.*, the sericitic character, and the more or less fractured condition. However, the evidence seems so strong that the two formations are distinct and unconformable, that the quartzite, dolomite and associated rocks belonging with them will be designated here as the Mesnard formation, from Mt. Mesnard, where the formation is well exposed.

Further study of the relations of the Mesnard formation to the Republic formation should be made both for their economic and scientific bearing upon the vexed question of the origin of the iron ores, and for the purpose of providing a guide to the explorer and prospector. Should the Mesnard formation subsequently be proved the same as the Republic, then it would appear probable that not only was a large portion of the ore of the latter a chemical replacement of dolomite, but also that the fragments of jaspilite and iron ore found in the Mesnard formation were derived from some formation below the Republic.

One great difficulty exists in the way of successfully working out the stratigraphy of this region. There is found above the Holyoke formation, and apparently unconformable with it, a series that is almost an exact counterpart of the arenaceous schist that lies below the Mt. Mesnard quartzite. This counterpart is represented by the graywacke which is particularly well developed in the vicinity of the Buffalo Mine. These arenaceous or graywacke series are peculiar in that they vary rapidly in texture, often passing into a coarse quartzite, with very irregularly interbedded argillitic bands. These irregularities are apparently not the result of current bedding, but are due to squeezing after the coarser portions of the rock were consolidated. For this overlying series the name Negaunee formation is proposed. This then gives part at least of the divisions foreshadowed in the above mentioned "Sketch of the Geology of the Gold, Iron and Copper Districts of Michigan."

Azoic or Archæan System of Michigan.	Laurentian Period (?)	—Cascade Formation.
	Huronian Period (?)	Republic Formation. Mesnard Formation.
	Michigan Period	Holyoke Formation. Negaunee Formation.

The above list gives the formations as now determined by the Michigan Survey, that make up the chief portion of the older rocks of northern Michigan, commencing with the oldest or underlying one—the Cascade.

One of the great obstacles in the way of successful exploration for iron ore has been that three or four different quartzites of the above formations have been confounded and ore sought for under each one. It is important that these quartzites should be carefully traced out and mapped, as well as that their relations to the iron ore horizons, should be more definitely settled.

Scheelite was found by Mr. Seaman at the Magnetic Mine. Dr. Rominger also reports its occurrence at that mine in his unpublished report for 1884.

During the past spring and summer, work has been continued upon the gas and salt wells.

The sections of these wells were, for the most part, made under Mr. Wright's administration, but no manuscript report to accompany them had been prepared by him. The material obtained from the borings has been again worked over by Dr. Lane and the sections have been amended from the new data obtained. In addition, whatever new material had accumulated has been worked out and new sections made.

Dr. Lane reports that his studies lead him to the conclusion that the rock formations thicken decidedly in going north, and that their thickness has generally been underestimated. The geological column is given as follows:

Quaternary	Drift, 3′ to 600′
Carboniferous	Woodville Sandstone, 0′ to 30′. Jackson Coal Group, 47′+. Parma Sandstone, 0′ to 200′. *First brine.*
Sub-Carboniferous	Grand Rapids Group, 300′+. Marshall Sandstone, 50′±. *Second brine.* Coldwater Shales, 667′ to 1000′+. Richmondville or Berea Sandstone, 65′. *Third brine.*
Devonian	St. Clair Shales, 150′–300′. Traverse Group, 100′–600′. Dundee Limestone, 40′–160′.
Upper Silurian	Monroe Beds, 100′–220′. - Below this only in borings. - Dolomite, salt and anhydrite, 650′–2000′. *Fourth brine.* Niagara Limestone, 350′+. Medina Red Shale, 100′+.

Lower Silurian....	Hudson River Shale, 420′+.
	Utica Shale, 80′.
	Trenton.

One interesting point developed is the presence of no less than four horizons that yield good brines, to say nothing of numerous other horizons such as the top of the Dundee or Trenton which yield strongly mineralized but impure brines. These latter brines are associated with indications of oil and gas. The second horizon, that of the Marshall sandstone, seems to be more permanent than some have supposed. One of the more important results is the probable identification over a good part of the State of the third horizon corresponding to the Berea sandstone. Toward the west it is less of a sandstone, and more of a red shale. By means of this horizon the Michigan Survey is able to indicate an extension hitherto unnoticed, of the Sub-Carboniferous across the south line of the State into Ohio and Indiana. A cluster of wells in the southeast part of the State shows that the boundary between it and the black shale crops out there and thus helps to settle a disputed point. The coal measures have also been shown to extend somewhat further than Rominger depicted them, both toward Sebewaing and probably toward Ludington.

The fourth brine horizon has been very extensively exploited, especially along the St. Clair river. North but not south of a line from Monroe to Kalamazoo, rock salt has been very generally found in connection with this horizon, not infrequently attaining an aggregate thickness of hundreds of feet. It lies quite deep (along St. Clair river at about 1600′), and a curious fact is that the sulphate of lime, with which it is always associated, is anhydrous. This horizon also furnishes the salt for the refineries along Lake Michigan, and has been shown to contain rock salt in the north part of the State, where it lies nearer the surface, and will in due time doubtless be extensively tapped.

Oil and gas occur in traces at several points, but nowhere enough to form a profitable industry, seemingly for lack of suitable reservoirs, such as might have been hoped to exist, from the indications found in the eastern part of Tuscola county. The great oil-bearing horizon of Ohio (the top of the Trenton) lies very deep, and is almost wholly unexplored. Along the outcrop of the black shale, wells have very often struck quite a little gas—one of the latest being at Mt. Clemens. At this well, and at others further north, the presence of sands at least nearly equivalent to that of Sylvania, Ohio, is interesting; and on the other hand, the phenomena reported by T. Sterry Hunt, of an apparent occurrence of the copper in the Lower Helderberg, finds a parallel in the Monroe and other wells in which this mineral is found.

In continuation of the analyses given in J.* are the following which were kindly placed at the disposal of the Survey by W. W. Manning, Esq., Agent of the Military Road Lands, and his assistant, Mr. O. Venstrom.

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* Numbered as Exhibit K in this volume.—S. S. B.

MILITARY ROAD LANDS.

Analysis of Roofing Slate from Sec. 2, T. 46 N., R. 37 W.

	Per cent.
Silica	54.84
Iron Oxide (protoxide)	9.43
Alumina	20.16
Lime	1.90
Magnesia	.95
Carbonic acid	1.42
Potassa	4.47
Soda	2.41
Phosphoric acid	.841
Sulphuric acid	.10
Loss by ignition	2.48
Water expelled at 212 deg. F.	.90
	99.901

Analyses of Clay. Red clay from Sec. 8, T. 47, R. 37:

	Per cent.
Silica	51.05
Iron Oxide	7.81
Alumina	21.42
Lime	1.93
Magnesia	3.73

Brown clay from Sec. 6, T. 47, R. 36.

	Per cent.
Silica	51.40
Iron Oxide	7.27
Alumina	16.43
Lime	5.40
Magnesia	2.88

ARTHUR UDDENBURG, *Analyst.*

Letters have been sent to all the known quarries in the State and an effort made to obtain material for making thorough tests of the building stones of Michigan, including their chemical and microscopic characters. As yet the returns are coming in very slowly from the quarries.

In drilling for building stone in the vicinity of L'Anse, the Detroit Brown Stone Company reports that a stream of water and some natural gas were struck at the depth of about seventy-five feet.

The position of the sandstone renders it improbable that gas in any useful quantity would be found, but I have had the water sent to me by the agent of the company analyzed by Dr. Geo. A. Koenig, who reports that the evaporation of three liters of the water gave 222.7 milligrams of solid residue. This residue was dried to 110° C, and then analyzed.

This analysis showed that in one million parts there are contained as total solids:

Calcium Carbonate	25.68
Magnesium Carbonate	4.71
Iron Carbonate	3.21
Sodium Silicate	15.20
Sodium Aluminate	4.30
Sodium Chloride	6.23
Sodium Sulphate	1.90
Parafine and other Solid Hydrocarbons	13.10
	74.33

The following assistants have been employed on the Survey since May 1, 1885:

1885.

F. H. Brotherton, topographer and woodsman.
A. E. Seaman, compassman.
Miss Helen L. Hopkins, clerk.

1886.

A. E. Seaman, topographer and woodsman.
George Rupp, topographer and woodsman.
Daniel Drummond, compassman.
Judson Seaman, compassman.
Miss Helen L. Hopkins, clerk.

1887.

A. E. Seaman, topographer and woodsman.
George Rupp, topographer and woodsman.
N. O. Lawton, compassman.
Chas. H. Rupp, compassman.
Miss Helen L. Hopkins, clerk.

1888.

A. E. Seaman, assistant geologist.
E. V. Smith, topographer and woodsman.
N. O. Lawton, topographer and woodsman.
Chas. H. Rupp, compassman.
F. A. Hollander, compassman.
C. L. Lawton, compassman.
F. P. Lawton, compassman.
Frank Drake, collecting and sketching.
Miss Helen L. Hopkins, clerk.

1889.

A. E. Seaman, assistant geologist.
A. C. Lane, petrographer.
N. O. Lawton. topographer and woodsman.

E. J. Longyear, topographer and woodsman.
L. B. Sutton, compassman.
W. L. Honnold, compassman.
W. J. Baldwin, compassman.
Miss Helen L. Hopkins. clerk.

1890.

A. E. Seaman, assistant geologist.
A. C. Lane, petrographer.
H. B. Patton, petrographer.
F. F. Sharpless, chemist.
W. L. Honnold. assistant.
Miss Helen L. Hopkins. clerk.

1891.

A. E. Seaman, assistant geologist.
A. C. Lane. petrographer.
H. B. Patton, petrographer.
L. L. Hubbard, petrographer.
H. F. Keller, chemist.
F. F. Sharpless, chemist.
W. L. Honnold, assistant.
Miss Kate Killian. stenographer and typewriter.

1892.

A. E. Seaman, assistant geologist.
A. C. Lane, petrographer.
H. B. Patton, petrographer.
L. L. Hubbard, petrographer.
H. F. Keller, chemist.
G. A. Koenig, chemist.
F. F. Sharpless, chemist.
J. B. Watson, draughtsman.
Miss Helen L. Hopkins, draughtsman.
Miss Kate Killian, stenographer and typewriter.
Miss Clara B. Webb, stenographer and typewriter.
Miss Helen Mary Ryan, stenographer and typewriter.

During the same time laborers, cooks and others have been employed in various parts of the work, as occasion required. With the exception of the clerk and one assistant, the employés of the Survey were, up to 1889, taken on to the force during the season of field work and discharged at its close. This gave a fluctuating body of assistants, who had generally to be trained from year to year to do the work required, and as none of them were in any sense geologists, their observations were only valuable to show the areal distribution of the rocks. They were excellent woodsmen, and for the work they were expected to do they generally gave satisfaction; but in geological work it seems necessary that the observer should have sufficient knowledge of geology to see whatever geological facts are shown in his district and to state them clearly, even if he is unable to draw any conclusions from them.

Owing to this fact the effort has been made to gather together a number of men skilled and trained in the line of work desired and needed on the Survey. This could only be done by offering places that would be continued from year to year. While this method gives less skilled woodsmen, it produces much better results for the scientific work of the Survey than the previous method. It also enables the office work to be brought up nearer to date than it did when almost all the force was employed in the field but not in the office. To perfect this organization, and to obtain the men desired. to provide sufficient office room for the work, case room for the specimens, apparatus and material, so that the necessary work could be done, has required much thought on the part of the State Geologist. The organization of the Survey cannot be said to have been in anywise perfected until 1891; and even now it is not complete in certain details, owing to lack of funds, etc. It would have been impossible to obtain so many and such skilled employés, had it not been practicable to occupy them partially with work in the Michigan Mining School as well as on the Survey, each organization paying *pro rata* for the time taken. This has, however. been explained in the past reports of the State Geologist.

Mr. A. E. Seaman has been connected with the Survey the longest of any one of the present staff. In his combined capacity as a woodsman and a field geologist it would be difficult, if not impossible, to obtain his equal in the State. He is familiar with nearly all the ground explored by the Survey, and has been of the greatest assistance in my taking up the work done under Mr. Wright's direction, as well as in numerous other ways, so much so, that I consider him an invaluable assistant for the Survey, and to him and to Mr. Wright are due much of whatever of value there may have been obtained from the field-work.

Mr. Seaman has had charge, from the first, of the collections and property of the Survey and the oversight of making the thin sections of the rocks, etc., etc.

Drs. Lane, Patton and Hubbard have been employed since they joined the Survey in petrographical and field-work, particularly in the former, for which they all have received a special European training.

Various other miscellaneous subjects arising out of the work of the Survey have been assigned to these gentlemen from time to time. Dr. Hubbard has further given special attention to the mineralogical side of the Survey work, and to the correction of the petrographical and other manuscript in preparation for the reports, work for which he has had exceptional training.

I am greatly indebted to all the assistants of the Survey for their kind coöperation, assistance and zeal in endeavoring to complete their work, furnish results, and to make the work successful in every way. The material obtained by them all has been freely drawn upon for my report, and for this they all deserve due credit.

Considerable of the time of the officers of the Survey, as heretofore, particularly that of the State Geologist, is occupied in answering various questions relating to the economic side of geology. These questions come, not only from our own citizens, but also from many others who are seeking raw materials for use in various industries. During the past years the questions have largely related to abrasives, building stones, limes, cements, metals and ores.

The tables given show that, since 1859, $96,799.40 have been drawn out from the Survey funds appropriated, and $60,607.85 returned to the State. The tables further show that from May 1, 1885, to January 1, 1888, there were expended under the direction of Mr. Wright, $16,051.06, while from May 1, 1888, to January 1, 1891, there have been expended under my direction, $27,597.16.

If time enough is given, the small appropriation allowed the Michigan Survey will answer, but to expect to make in a few years a complete Geological Survey of a state larger than England, with the reports completed and published, on much less money a year than it costs to sink a single drill hole for gas to the Trenton formation in the Lower Peninsula, or to make a single decent exploration for iron or copper in the Upper Peninsula, is to expect the impossible. So true is this, that only one single report of all those ever published by the Geological Survey of Michigan has been anything except a preliminary report, or a report of progress. The one exception is Dr. Rominger's Report on Fossil Corals. The difficulty has lain in the small means furnished the Survey, the popular demand for haste, the death of two State Geologists, and the quite frequent changes amongst the others and their assistants, all with their reports and work unfinished.

The proposed conditions of friendly and harmonious work between the Geological Survey of Michigan and the United States Geological Survey are given in the correspondence affixed to the report of the State Geologist for 1889-1890. The work of the State Survey had then progressed so far in certain directions that but little advantage could be taken of this arrangement until that work could be closed and published; yet all work on the State Survey since that time has been done with the aim of dropping, in the near future, all the field work relating to the areal distribution of the rocks or to general problems of scientific interest, except so far as they bear upon points of economic interest. Had the means at the command of the State Geologist been sufficient, advantage could have been taken of the alliance at once, but as it was, he could only endeavor to complete the work already undertaken, hoping in the near future to devote the means at his command entirely to the economic side of geology, leaving the other side to the United States Survey. Very many friendly courtesies have been extended between the two Surveys, and the United States Survey has sent to the State Survey photographic copies of its topographical maps, as well as given it the use of thin sections of rocks and other material. The State Geologist hopes that the present friendly relations will never be disturbed, all the more because the mutual advantages to both organizations belong rather to the future than to the past.

The State Survey is greatly hampered in its work by its small appropriation, which is only two-thirds as much now as the State appropriated annually for this work in 1837 and during several subsequent years. As it is, the Federal Survey is able to, and did, put into the field in Michigan last year over fifty men, while the State could send only six, and those for only a portion of the time.

The Survey is further hampered by the injurious and absurd regulation of the State, so far as it relates to educational and scientific organizations, that no appropriation can be overdrawn in any one year, to be paid out of the past or future appropriations, and that every dollar saved in any year must be returned to the State and not used when it is more needed. This denies to every official any chance to economize at one time, in order to enable better and more valuable work to be done under other and more favorable conditions. It could well be entitled an act to prevent the State from obtaining that for which it has made its appropriations, and which it has a right to expect.

In an effort to obtain a much needed topographical map of Michigan, upon which the geology can be delineated, some correspondence has been had with the United States Geological Survey. The Director of that Survey reports that in his judgment "the State of Michigan can be mapped on a scale of one mile to the inch and with a twenty foot contour interval, at a cost not to exceed $8 per square mile, or about $475,000 for the State."

Experience shows that while $8 may be the average for the entire State, in the Upper Peninsula the cost per square mile would be much more, owing to the greater difficulty of the work. When coöperation has existed heretofore between State Surveys and the United States Survey, the expenses have been equally shared between them, under such mutual arrangement and supervision as has been determined upon. The State Geologist recommends that the Legislature be asked to appropriate a fixed sum per year, extending over a period of years, the United States Survey contributing an equal amount, for the purpose of making the above-mentioned topographical map of Michigan.

The amount appropriated would depend upon the quickness with which the State desired the work to be completed; for example, if the Legislature appropriated only $16,000 a year, it would take about twenty-four years to complete the work, but if $40,000 were appropriated, six years should suffice.

Encouragement has been given the State Geologist that the United States Coast and Geodetic Survey would undertake a further and more complete triangulation of the State of Michigan than had been made theretofore by the United States Engineers. In accordance therewith, the Superintendent of the Coast Survey informs me that a reconnoissance was made to determine the work necessary to connect Lakes Erie and Huron. It was found "practically impossible to make anything like a successful triangulation between these points without enormous expense." The Superintendent further states that owing to the small amount of money available for State work, it is hardly possible for the Coast Survey to do anything in Michigan. He hopes, however, to execute a line of levels along the southern boundary of the State to connect Lakes Erie and Michigan.

Very respectfully,
M. E. WADSWORTH.

MICHIGAN MINING SCHOOL,
Houghton, Michigan, Oct. 17, 1892.

A SKETCH OF THE GEOLOGY

OF THE

IRON, GOLD AND COPPER DISTRICTS

OF MICHIGAN.

BY M. E. WADSWORTH.

EXHIBIT K.

PREFACE.

The sketch here given is an abstract of material collected by the Michigan Geological Survey since May, 1885, and by myself independently prior to my appointment as State Geologist in 1888.

The death of my predecessor in the midst of his work has greatly retarded the publication of the reports of the Survey, which has now accumulated material enough to fill, when worked up, several volumes. This would naturally include the evidence upon which the conclusions given in this sketch are based, including the field and microscopic work, numerous maps, figures, etc. In such a publication it is intended to give full credit to the observations and work of others in the same lines of investigation, which time and space allow to be done now only imperfectly.

MICHIGAN MINING SCHOOL,
Houghton, Michigan, March 26, 1892.

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  (*a*) Special observations east of Gogebic Lake; (*b*) Statements of Brooks and Pumpelly; (*c*) Statements of Irving; (*d*) Observations of the Michigan Survey; (*e*) Observations of the Michigan Survey west of Lake Gogebic; (*f*) Supposed fault line along the lake.

CHAPTER VIII.

VEINS AND COPPER DEPOSITS.

§ 1. Cross faults on Keweenaw Point:
  (*a*) Formation of the veins; (*b*) The water action and its temperature; (*c*) Minerals formed by chemical deposition from the water, and its course; (*d*) Occurrence of the copper; (*e*) Impregnation of the lava with copper; (*f*) The so-called ash bed of Copper Falls; (*g*) Impregnation of conglomerates and replacement of pebbles by copper.

§ 2. Classification of the copper deposits of Keweenaw Point:
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CHAPTER IX.

THE MINERALS AND ROCKS OF MICHIGAN.

§ 1. Miscellaneous analyses:
  (*a*) A new mineral or variety from the Champion Mine; (*b*) Analyses of picrolite; (c) Analyses of chloritoid and gruenerite; (*d*) Analysis of a clay; (*e*) Analysis of a mineral oil; (*f*) Analysis of mine water.

§ 2. Macroscopic Minerals found in Michigan:
  (*a*) Lower Peninsula; (*b*) Upper Peninsula.

§ 3. Microscopic characters of rocks and minerals of Michigan:
  (*a*) Granite rocks; (*b*) Syenites and diorites; (*c*) Quartz diabases; (*d*) Lamprophyres; (*e*) Serpentine; (*f*) Amphibolites and hornblende schists; (*g*) Chlorite schists and the formation of iron ores; (*h*) Spilites and andesites; (*i*) Sandstones, arkoses, and quartzites; (*k*) Slates and graywackes; (*l*) Chloritoid; (*m*) Gruenerite; (*n*) Perofskite, fluorite and chlorite; (*o*) Garnet; (*p*) Augite; (*q*) Titanium minerals.

§ 4. Microscopic study of some Michigan Rocks:
  (*a*) Dike rocks; (*b*) Diabase altered to kaolin and quartz; (*c*) Hornblende picrite.

SKETCH OF THE GEOLOGY OF THE IRON, GOLD AND COPPER DISTRICTS OF MICHIGAN.

CHAPTER I.

INTRODUCTORY.

§ 1. It is proposed to give in the following pages an abstract of the results obtained by the Michigan Geological Survey, under the administration of the late Mr. Charles E. Wright, State Geologist, and myself; as well as of some independent work.

In this abstract an effort will be made to give a connected discussion of the different formations and their general relations, together with some of the evidence upon which the general conclusions of the State Geologist rest. It is to be remembered, however, that these conclusions are but provisional, and that many of them will doubtlessly be modified by further evidence when the data are more fully worked out.

In the preparation of this paper I am greatly indebted to the assistants of the Michigan Survey—Messrs. Lane, Patton, Hubbard and Seaman, and to the preceding work of Mr. Wright.

The first three have given special papers of their own which are appended, but particular acknowledgment is due to Messrs. Wright and Seaman, since their work has been directly incorporated in the text of this paper.

§ 2. The region about the south shore of Lake Superior is to geologists one of the most interesting districts of the United States, embracing as it does, in a limited area, old crystalline rocks, together with forms that are almost in their original condition of a beach sand and mud. In this classic region of Michigan was first established the base of the geological column, the Azoic System of Foster and Whitney, or the Archæan of Dana. Overlying this system are found the sandstones and limestones of the Paleozoic, with their interbedded lava flows.

These systems possess a strong economic interest, owing to the stores of iron in the Azoic and of copper in the Paleozoic of this district, which make the Upper Peninsula of Michigan one of the most important mining regions in America.

The geology of this section is so difficult and complicated that, in its general discussion, perhaps no proposition can be stated concerning any portion of it, to which exceptions cannot be taken. Indeed, out of the general discussion of different points comes in time the truth, and various geologists, even now, are working over this region in the endeavor to arrive at some concensus, or at least to determine upon what points they can agree, and upon what points difference of opinion will have to exist between them, until further evidence can be obtained. I shall endeavor to give in a brief form that which appears to me at present to be the more correct statement of the geological structure of the region, admitting that, as more complete evidence shall be obtained, I may change my views from time to time in the future as I have done in the past, if that evidence shall cause me to believe that I have been mistaken.

§ 3. The geological formations found in the State of Michigan, as determined by the members of the State Geological Survey and others, are considered to be as follows, the lowest formations given first:

UPPER PENINSULA.

Azoic, or Archæan		Cascade.	
		Republic.	
		Holyoke.	
Paleozoic	Cambrian	Potsdam.	
		Calciferous	100 feet of calcareous or dolomitic rock. Not easily separated from the Potsdam.
	Lower Silurian	Trenton	75 feet of dolomite.
		Hudson River	60 feet shales and arenaceous limestones.
	Upper Silurian	Niagara	100 feet of dolomite, argillaceous at the base, thick-bedded in the middle portion, and on the top thin-bedded and siliceous.
		Onondaga	Only a few feet in thickness so far as is known. Gypsiferous marl and dolomite.
	Devonian	Lower Helderberg	150 feet of dolomite.
		Upper Helderberg	100 feet of bedded limestone having cherty and shaly layers and a brecciated base.
Anthropozoic	Quaternary	Pleistocene.	
		Recent.	

The term Azoic is retained here without regard to the question of the presence or absence of life in that era. I take this ground since that term was in good and current use for some twenty-five or thirty years, and there were no reasons for its disuse that do not apply to a large part of the scientific terms now current in geology, except the purely personal reasons that caused the substitution to be made. Who can at present say that the term Azoic is not far more appropriate to the rocks so designated by Foster and Whitney in 1850, than are the terms Triassic, Tertiary, Quaternary, and many others now used by geologists? A scientific name means that for which it was originally used, and not necessarily what its Greek components signify.

The terms Cascade, Republic and Holyoke were used by me in 1891* for three formations whose unconformable relations had been made out by the Michigan Survey. These formations are discussed more fully later in this sketch, but it may be remarked here that both the Cascade and Holyoke show some evidence that further study may lead to the division of each into two or more unconformable subdivisions. The names are taken from prominent localities where the formations are well developed. The Holyoke formation presents many points of resemblance to the Acadian of Dawson and Dana.

The Cambrian is subdivided by most Geologists at the present time into the Keweenawan and Potsdam, commencing with the lower, as follows:

Cambrian	Keweenawan	Lower Keweenawan	25,000 ft. (?) of interbedded sandstones, conglomerates and lava flows, with some intrusions.
		Upper Keweenawan.	12,000 ft. (?) of sandstone and shale not separable from the Potsdam sandstone.
	Potsdam, or Eastern Sandstone	700 ft. (?) of red and white sandstone, conglomerate and shale.	

§ 4. The formations of the Lower Peninsula are quite different, and none lower than the Lower Helderberg are exposed on the surface, the lower formations given being known only through drillings, etc.

The table, as before, commences with the oldest formations:

LOWER PENINSULA.

Paleozoic	Lower Silurian	Trenton. Silurian shales	700-900 feet. Dark bluish gray.
	Upper Silurian	Medina (or Clinton)	Not positively determined. Provisional name given to 50 feet of reddish sandstone and arenaceous limestone.
		Silurian limestones	650–1,700+ feet. Generally dolomitic; growing thicker toward the north and east, and containing massive layers of anhydrite and rock salt near and below the middle of the series, to which the increased bulk of the series seems largely due.

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* A sketch of the Geology of the Marquette and Keweenaw Districts, 2d edition, 25 pp., by M. E. Wadsworth, in "Along the South Shore of Lake Superior," by Julian Ralph, New York.

Paleozoic	Devonian	Oriskany (?)	Does not appear to be present as a fixed horizon, but in local deposits of angular current-sand at different levels in the Helderberg limestone.
		Upper Helderberg	100 feet of buff, now dolomitic, often cherty limestones; often bearing brine or some gas.
		Hamilton	130–230 feet of bluish shales and shaly limestones of variable amount of lime, and of varying thickness.
		Ohio black shales	300–350 feet. Bituminous at the bottom and passing, on top, into carboniferous shale.
	Carboniferous	Berea (?) sandstone	40 to 150 feet. Passes into a red sandy shale and is perhaps wanting at some points.
		Waverly shales	1,000 feet. Subdivided by more or less calcareous, arenaceous, carbonaceous and argillaceous bands which are persistent. Brine-bearing at various horizons.
		Marshall sandstones	100–200 feet.
		Subcarboniferous (?) limestone	520 feet of strata, variable in character and thickness; often gypsiferous, arenaceous, or shaly.
		Parma conglomerate.	About 100 feet.
		Coal measures	About 300 feet.
Anthropozoic	Quaternary	Pleistocene. Recent.	

CHAPTER II.

AZOIC SYSTEM.

§ 1. *The Azoic, or Archaean System* south of Lake Superior consists of rocks that have been formed in three ways:

1st. By mechanical means.
2d. By eruptive, igneous, or volcanic agencies.
3d. By chemical (including electro-chemical) action.

§ 2. *Fragmental, or Detrital Rocks.*

The mechanical agencies of the Azoic time acted upon some earlier formed rocks, in like manner as we see rain, winds, waves, frost, etc., now breaking down the rocks of the present day, causing them to be deposited as soil, mud, sand and shingle, forming detrital, or sedimentary deposits. Such detritus one can see upon the shores of any lake or sea. This material in many localities is variable in its composition, and oftentimes abruptly changes from fine mud to sand, or even to coarse shingle. At other localities upon the same lake shore one may observe a nearly uniform sand, mud or shingle stretching away as far as the eye can reach. Like uniformity and like abrupt changes are seen by the geologist to occur in the rocks formed from the ancient sands, muds and shingle of the early seas and lakes. These deposits may have remained on the surface of the ancient beach, or may have been deeply buried under succeeding deposits; but whatever may have been their position relative to the earth's surface, for the most part they have been greatly changed or altered from their original condition.

(*a*) It is found that these old muds, sands and shingles have been acted upon and metamorphosed, or altered, by heat from the earth's molten interior, or by contact with igneous or volcanic rocks with their accompanying hot waters. Or, again, these deposits have been affected by hot or cold waters percolating through them, bearing materials which chemically acted upon them; or, again, they may have been subjected to greater or less squeezing, pressure and folding.

Of all the agents of consolidation and change in rocks, the chemically active waters are, to my mind, the most potent; and it appears to me probable that heat and pressure alone would be unable to produce any general and widespread rock alteration, if it were not for the intervention of the percolating waters found in all rocks, so far as man has been able to penetrate the earth. Such metamorphosed or altered detritus forms the oldest known rocks of the Lake Superior district, and but little is known of the original rocks, except the story told by the remains of that debris now found in the old metamorphosed rocks. From the character of the debris it appears that the original rocks were of igneous or volcanic origin; that is, such rocks made up the early formed crust of the earth, or else they were produced by the earth's primitive volcanic activity.

When the muds, sands or shingles have been consolidated they are found to form rocks that differ, not only in the fineness of material in them, and in their chemical and mineral composition, but according as they have been subjected to different agencies and conditions.

Thus it is that the disintegrated rocks have formed the muds known as the argillites, shales, most schists, and some gneisses; the sands have formed sandstones, quartzites, some schists, and most gneisses; while the shingle finds its expression generally in the conglomerates.

(*b*) The term argillite is here used to indicate those consolidated muds that were largely composed of clay or argillaceous material; but the argillites are commonly known as slates, a term properly applied to an argillite only when it has been subjected to pressure and chemical action to such an extent that it has the property of cleavage. In the Azoic district of Northern Michigan argillite is abundant, the common forms being found along the lake shore and inland south of Marquette. It occurs at Ishpeming and Negaunee, in the vicinity of the mines, forming, with the chlorite schist, the principal country rock. Argillite also exists in abundance at most of the mines in the Menominee and Gogebic Ranges, and is found at various points between these ranges on the one hand, and the Huron Mountain region on the other, forming in some portion of its extent an excellent slate, which is worked in the vicinity of Arvon. The L'Anse argillite occurs in the carbonaceous and graphitic varieties, and passes into a slate. It is the graphitic variety of argillite, forming the country rock of Sec. 33, T. 50, N., R. 33 W., that has been quarried or mined under the name "Baraga graphite," the carbonaceous material forming a constituent portion of the country rock, and not a vein, as has been reported. A similar argillite is also found on the southern side of Teal Lake, and at the mines in the vicinity of Crystal Falls and Iron River.

(*c*) When a sandstone has been greatly altered or indurated, so that it is composed of a very hard, compact mass of quartz grains, it forms a variety of sandstone here called quartzite, a very common rock in the vicinity of Marquette and Negaunee, and much quarried for use in lining furnaces, etc. Some of the well-known localities are near the Marquette State Prison, Mt. Mesnard, and northeast and northwest of Teal Lake, in the immediate vicinity of the latter. It is also abundant about the Jackson, Cleveland, New York, Republic and Champion iron mines. Quartzite also is found flanking the gneissoid and granitic rocks from Sturgeon river, northwesterly, to Sec. 2, T. 40, R. 30 W. The same rock occurs in T. 41, R. 30 and at various places in the Felch mountain district and elsewhere.

(*d*) The terms schist and gneiss are here used to designate all those altered, or metamorphosed detrital deposits, whose minerals are arranged in more or less parallel bands, along which the minerals tend to lie flatwise or lengthwise, causing the rock to split into more or less regular plates parallel to these bands. This foliation may or may not coincide with the planes of sedimentation, and in the majority of cases in the Marquette region it does not. A striking example of this can be seen in the schist north of Teal lake, where the planes of deposition run approximately northeast and southwest, while the foliation runs east and west. Amphibole schists are well developed about Marquette, forming much of the rock underlying the northern portion of the city, especially about Light House Point and the region adjacent. Chlorite schist occurs commonly with argillite in the vicinity of Marquette, and about the iron mines of Negaunee, Ishpeming, Champion, and Michigamme, forming in places even more of the country rock than the argillite, which latter is sometimes wanting.

Gruenerite schist and mica schist occur in the vicinity of Republic, Humboldt and Champion, while chloritoid and ottrelite schists are found in the vicinity of the last two named mines, the Fitch mine and at Palmer. Conglomerates are found in the vicinity of most of the iron mines, also by the Republic branch railroad near Humboldt, as well as in the vicinity of Deer lake and Silver lake.

§ 3. *Eruptive, Volcanic, or Igneous Rocks.*

To obtain a fair idea of rocks of this character it is necessary to do as we have done with the detrital or fragmental rocks; that is, to observe carefully the recent forms and trace out their structure and various modifications and alterations. If this is done, we see that the eruptive rocks are changed, or metamorphosed as much as, and oftentimes more than, the sedimentary formations.

(*a*) The eruptive rocks, coming in a liquid state from the interior of the earth, cannot endure unchanged the conditions which exist at or near the earth's surface. They are in an unstable condition, and must be made over so as to possess a more stable mineral composition. The agencies that produce the change appear in general to be the same as those which alter the sedimentary formations, that is, percolating waters chemically active, pressure, and heat or cold. The first change is the change from a liquid or pasty mass into a solid one; later there comes a more or less variable alteration that extends throughout the entire mass, and causes a variation in the mineral composition and structure—so much so that at times no traces of the rock's original condition remain, unless they be its form or its relative position to other rocks.

It is these changes that cause rocks that were originally peridotites, or olivine rocks, to be now called serpentines, actinolite schists, talc schists, dolomites and verde antiques; or cause formerly molten basalts to be now called melaphyrs, diabases, gabbros, diorites, eclogites, amphibolites, hornblende schists, chlorite schists, mica schists, amygdaloids, traps, greenstones, variolites, granites, etc.

It may here be said that schists result very commonly from the alteration of eruptive, as well as of sedimentary rocks.

It is this general alteration that causes rocks that were formerly andesites now to form rocks that are called phonolite, propylite, hornblende porphyry, porphyrite, diabase, melaphyr, diorite, granite, schist, etc. In the same way those that were once trachytes now form felsites, phonolites, porphyries, granites, gneisses, etc.; while the rhyolites, in their alteration, form rocks called felsites, petrosilex, gneisses, granites, quartz porphyries, etc. It will be inferred from the above that the alteration of eruptive rocks produces, from forms that were originally distinct, forms that are now known by the same name; while, on the other hand, the varieties due to the various changes in a single rock species are very numerous.

(*b*) The structure of eruptive rocks differs very much according to their composition; according to the conditions under which they have cooled, whether slowly or rapidly; according to the conditions in which they have reached their present position relative to their associated country rocks; and according to the conditions to which they have since been subjected.

Classification of rocks.

§4. In order that the rock nomenclature used in this paper be fully understood, there is here given in accordance with the preceding principles a classification of rocks. Although this has been used to a greater or less extent by me in class instruction since 1876 and in my various publications in naming the rocks described, it has never been published in full before its use in this article.*

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*See Bull. Mus. Comp. Zool., 1878, V, 39, 40, pp. 275-287; 1880, VII, 1-164, 183-187. 331-565; Proc. Bos. Soc Nat. Hist., 1877, XIX, 217-237, 309-316; 1880, XXI, 91-103, 243-274, 288-294; 1883, XXII., 412-432, 485-489; 1884 XXIII, 197-211:
Mem. Mus. Comp Zool., 1884, XI, 208 pp.:
Am. Jour. Sci., 1884 (3) XVIII, 94-104;
Science, 1883, I, 127-130. 541; 1884, III. 486, 487; IV, 111;
Bull. Minn. Geol. Survey, No. 2, 159 pp.

CLASSIFICATION OF ROCKS.

(*a*) *Eruptive (including Meteoric) Rocks.*

Family or species.	Unaltered structural varieties.	Unaltered mineralogical varieties.	Altered structural varieties.	Altered mineralogical varieties.	Fragmental varieties.	Altered massive and fragmental varieties.
Siderolite.		Meteoric Iron. Terrestrial Iron.		Magnetite. Menaccanite. Martite. Hematite.	Tufa Porodite.	Limonite, etc.
Pallasite.		Pallasite.		Cumberlandite.	Tufa. Porodite.	Serpentine. Amphibole Schist.
Peridotite.		Dunite. Saxonite. Lherzolite. Buchnerite. Wehrlite. Picrite.		Eulysite. Hornblende Picrite.	Tufa. Porodite.	Serpentine. Ophicalcite. Dolomite. Talc Schist. [Steatite.] Amphibole Schist.
Basalt.	Tachylite. Basalt. Anamesite. Dolerite.	Enstatite Basalt. Hypersthene Basalt. Pyroxene Basalt. Nephelinite or Nepheline Basalt. Leucitite or Leucite Basalt. Melilite Basalt.	Zirkelite. Melaphyr. Diabase. Gabbro.	Diabase. Gabbro. Norite. Theralite. Diorite. Minette. Syenite. [Augite Syenite.] Granite.	Tufa. Porodite.	Argillite. Phonolite. Granulite. Amphibolite. Amphibole Schist. Hornblende Schist. Actinolite Schist. Gruenerite Schist. Eclogite. Epidosite. Chlorite Schist. Talc Schist. [Steatite.] Mica Schist. Gneiss.

Andesite.	Shastalite. Andesite.	Enstatite Andesite. Hypersthene And'te. Pyroxene Andesite. [Augite Andesite.] Amphibole Andesite. [Hornblende Andesite.] Mica Andesite.	Weiselbergite. Phonolite. Melaphyr. Felsite. Porphyrite. Diabase. Gabbro.	Phonolite. Propylite. Mica Andesite. Minette. Dacite. Gabbro. Norite. Diorite. Syenite. [Elaeolite Syenite.] Granite.	Tufa. Porodite.	Argillite. Granulite. Amphibolite. Amphibole Schist. Epidosite. Chlorite Schist. Mica Schist. Gneiss.
Trachyte.	Lassenite. [Pumice.] Trachyte.	Enstatite Trachyte. Hypersthene Trach. Pyroxene Trachyte. Amphibole Trachyte. Mica Trachyte.	Metabolite. Phonolite. Felsite. Syenite.	Phonolite. Dacite. Diorite. Syenite. Granite.	Tufa. Porodite.	Argillite. Granulite. Mica Schist. Gneiss.
Rhyolite.	Obsidian. [Pumice. Pitchstone. Pearlite. Spherulite.] Rhyolite. [Liparite.] Nevadite.		Felsite. [Quartz Porphyry.] Microgranite. Granite.	Granite. [Aplite. Greisen.]	Tufa. Porodite.	Argillite. Granulite. Halleflinta. Quartz Schist. Mica Schist. Gneiss.
Jaspilite.					Porodite.	Ferruginous Schist. Quartz Schist. Halleflinta.

CLASSIFICATION OF ROCKS.—CONTINUED.

(b) *Sedimentary Rocks.*

Family or species.	Unconsolidated structural varieties.	Unconsolidated mineralogical varieties.	Consolidated structural varieties.	Consolidated mineralogical varieties.	Altered structural varieties.	Altered mineralogical varieties.	Structural and mineralogical sub-varieties.
Laxite.	Mud. Sand. Gravel. Shingle. Marl.	Clay. Loam. Marl.	Shale. Sandstone. [Graywacke.] Conglomerate. Breccia. Merolite.	Argillite. [Graywacke.] Marl. Limestone. Dolomite.	Slate. Porcelanite. Schist. Quartzite. Conglomerate. Gneiss. Breccia. Merolite.	Slate. Gneiss. Marble.	Andalusite Schist. [Chiastolite Schist.] Chloritoid Schist. Ottrelite Schist. [Phyllite Schist.] Talc Schist. Chlorite Schist. Amphibole Schist. Hornblende Schist. Actinolite Schist. Gruenerite Schist. Mica Schist. Sericite Schist. Staurolite Schist. Graphite Schist. Quartz Schist. Ferruginous Schist. Jaspilite. Halleflinta. Protogene.
Haloidite.		Halite, or Salt.		Halite, or Salt.			
Ferrolite.				Pyrite. Limonite. Hematite. Magnetite. Menaccanite.			Martite.
Corundolite.				Corundum. Emery.			
Silicalite.	Infusorialite, or Diatomaceous earth.		Tripolite. Fiorite. Sinterite. Millite.	Opalite. Quartz.			Quartz. Hornstone. Lydite. Jasper.

Manganolite.		Wad.	Bog Manganese, or Manganesite.	Wad. Psilomelane. Pyrolusite. Manganite. Rhodonite.			
Phosphorolite.	Guano.		Guano. Phosphorite. Coprolite.	Apatite.			
Barolite.				Barite. Celestite.			
Selenolite.				Gypsum. Anhydrite.			
Limestone.	Marl.	Chalk. Marl.	Travertine. Marl. Limestone.	Limestone. Dolomite. Magnesite.	Marble.		Ophicalcite.
Carbonolite.	Turf. Peat.		Lignite. Torbanite. Cannelite. Bituminosite.	Asphaltum. Coal. Graphite.	Albertite. Anthracite.		

(*c.*) In the classification of rocks it would appear that some scheme should be adopted that would be natural,—one that the geologist can use without entering upon all the refinements of minute microscopic and optical mineral analysis. Whatever special distinctions are shown to exist between the different rock species, if of sufficient importance to be used to designate variety or specific characters, ought to be manifest to the eye, with the aid of the pocket lens, in more or less marked features of the rocks themselves, so that they can be used in the field and with the hand specimen. In my petrographical work the effort has been to correlate the physical, the mineral and the microscopic characters in such a way that the geologist in the field can make use of the nomenclature with more or less certainty, depending upon his knowledge and his accuracy of observation. The general principles found from empirical study indicate that there are certain types, or families, or species of the eruptive or massive rocks which are to be seen unchanged in the meteorites and unaltered volcanic rocks, while the great mass of the so-called species or families are simply altered or degraded forms of the first mentioned unaltered types. That is, the older rocks now classed as distinct species, or as families, were, in their original condition, identical with their younger prototypes,—the present difference being due to alteration and conditions of crystallization, since denudation reveals forms of the older rocks that were more slowly cooled than any we now see on the exposed surfaces of the younger rocks. Accompanying this alteration are greater or less changes in the structure and mineral composition, all of which manifest themselves more or less plainly in the field and in the hand specimen.

These changes appear to be chemical or molecular; the entire rock partakes of them to a greater or less extent.

As is more fully explained in the chapter relating to ore deposits, this alteration is due mainly to the passage of the rocks from a less stable to a more stable chemical composition, or to the degradation and dissipation of their energy.

In a classification based on the above principles all rocks in every form and gradation, or stage of alteration, need to be studied, and therefore the classification above given can be considered only as marking the present stage of the work, and as by no means a final one.

(*d*) It has not been found in accordance with the natural or field occurrence of rocks to name them differently according to their geological age, or according as they are in masses, dikes or flows. The use of geological age is objected to because the supposed differences marked by age are due rather to the conditions to which the rocks have been subjected, some modern rocks often being far more altered than some ancient ones. The classification of rocks by their occurrence in masses, dikes or flows is objected to, since the same individual rock may be seen to pass from the mass into the dike, and from the dike into the flow; and the structure supposed to belong to the mass can be found in the thicker dikes and flows. This should prove that there is no natural distinction of character founded on the mode of occurrence of these rocks; all that is required is that the lava shall be in sufficient quantity to cool slowly. This is especially the case on Keweenaw Point, where gabbros, diabases, melaphyrs, etc., can all be found as flows.

(*e*) All the characters of a rock are here taken into consideration in attempting to decide its place in the classification, and the effort is made, when practicable, to place in one family or species all rocks of the same type, whatever may be their structure or stage of alteration, or whether they are fragmental or not. It can be seen that originally the eruptive rocks in their less altered states were named largely on account of their structure, mineral composition and fragmental condition, and that in their altered states the names were apt to be varied according to the same factors.

(*f*) As in the classification of plants and animals, no hard and fast lines can be drawn between the species or families on account of their evolution of advance from the lower to the higher, so in the classification of rocks no hard and fast lines can be drawn between the families or species, on account of their evolution of degradation from the higher towards the lower states.

In this sketch space does not permit me to give the diagnostic characteristics of each family or species or variety. The effort is made to use the terms in accordance with their general significance, as employed by geologists and petrographers, adding such new terms as seem advantageous in the present stage of the science to bring out the relations of the different forms. In this classification all rocks are included, whether meteoric or terrestrial.

(*g*) So far as studies have been made in this direction, it appears that the families or species have general limits of chemical composition within which the normal forms generally fall. and outside of which they rarely go, except when abnormal or when much material has been carried into or removed from them by the agency of the percolating waters. The general result of alteration, so far as it affects the chemical composition, appears to be to remove the bases and relatively to increase the percentage of silica, carbonates, etc., and to diminish the specific gravity.

In the meteoric siderolites the iron averages from 80 to 97 per cent. In the pallasites of meteoric orgin the iron averages about 60 per cent., and the silica ranges from 3 to 33 per cent., averaging about 20 per cent.

Of the typical cumberlandite two analyses were made by Prof. R. L. Packard, in order to ascertain its general composition. No. 1 was made from a piece containing feldspar, and No. 2 from a piece showing no feldspar. The analyses show no special difference between the two specimens, except that one was somewhat more hydrated than the other.

ANALYSES OF CUMBERLANDITE.

	No. 1.	No. 2.
SiO_2	20.85	20.77
Al_2O_3	5.26	4.01
Fe_2O_3	16.32	17.22
FeO	28.53	26.51
CaO	0.98	0.53
MgO	17.60	17.96
TiO_2	9.63	10 08
H_2O	0.66	2.70
	99.83	99.78

Analysis of the feldspar made by Professor Packard gave the following result:

SiO_2	50.31
Al_2O_3	27.43
Fe_2O_3 FeO	3.79
CaO	10.75
MgO	2.11
	94.89

Although the feldspar was separated as completely as possible, the above analysis shows that the separation was not complete.

Of 193 analyses of different peridotites, both terrestrial and meteoric, only five show more than 45 per cent of silica, and none less than 26 per cent. All but eleven show between 30 and 45 per cent of silica, while in the great majority the silica ranges between 33 and 34 per cent.

In the basalts the percentage of silica usually runs from 45 to 55 per cent., averaging about 49 per cent., although in some of the leucite and nephelite rocks it is found to be much below 45 per cent. and opens the question whether they do not belong rather to the peridotites than to the basalts, particularly as they usually contain a relatively high percentage of magnesia.

The andesites range usually from about 55 to 65 per cent. of silica, averaging about 58 or 59 per cent. The trachytes range from 62 to 68 or 70 per cent. of silica, averaging somewhere about 66 per cent.; but the limits of their chemical constitution are in every respect at present quite poorly defined. The rhyolites vary usually from 68 to 78 per cent. of silica, averaging about 73 per cent., while the jaspilites range from 78 or 80 per cent. upwards. The analyses given in this sketch place the silica between 80 and 81 per cent.

In this classification the term "unaltered" does not mean that no change has occurred in the rocks, but simply that whatever alteration has taken place, has not gone far enough to prevent the general recognition of the rock and its usual classification with the strictly unaltered type.

The term tufa is used for the comparatively unaltered ashes or debris of the eruptive rocks, and the term porodite, proposed in 1879, for all the altered fragmental forms or tufas commonly called diabase tufa, schalstein, etc.

(*h*) In 1883 (Science pp. 127-130) I stated that all the metorites I had studied by the aid of the microscope were not fragmental, although they had been almost universally described as such. A subsequent examination of the collections at London, Paris, Vienna, Strasburg. and elsewhere only confirmed my previous observations.

My conclusions published in 1883 concerning the structure of the meteorites were sustained in 1885 by the great authority of Brezina,* the Curator of the Vienna collections, although any one reading Fletcher's work† upon this point would naturally conclude that I had followed Brezina instead of preceding him by over two years, in concluding that the chondritic structure of the meteorites was due to crystallization.

In my "Lithological Studies," published in 1884, the same ground was taken, but two forms (Orvinio and Chantonnay) were described as tufas on the authority of Tschermak. The sections of these forms I first saw in

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* Die Meteoritensammlung, 1885, p. 168.

† An Introduction to the Study of Meteorites, 1886, p. 38.

1885 at Vienna. They were shown me by Brezina, who stated that he did not consider them as fragmental. My study of these sections confirmed the observations of Brezina (not then published) and showed that the apparent fragmental structure was due to a difference of coloration in the mass. The differently colored parts were taken by Tschermak as fragments cemented by a matrix, but I found that the supposed fragments and matrix formed the same continuous mass, and that there was no mineralogical break to correspond with the change in coloration.

It may be stated here that I have never studied anywhere a single meteorite that did not show evidence that appeared to me indisputable, that it was not fragmental, but that all the supposed fragments and chondri are continuous with and constituent portions of the general mass, just as much as are the pearls and spherules in the rhyolitic rocks.

(*i*) In the case of the cumberlandite the form containing feldspar was found by field observation in 1885 to pass into the form containing only greenish spots of serpentine and amphibole. Feldspars were found then showing various gradations in the alteration to the serpentinous product. While much of the talc schist is apparantly due to the alteration of olivine rocks, yet part of it, like some soapstones, seems to result from the change of an amphibole or anthophyllite rock. Various schists and argillites appear as common products in the extreme alterations of all the eruptive rocks, whether in the fragmental or massive forms; and although in the classification they are placed in the family in which they are considered to belong as having been derived from the typical forms by alteration, yet, in speaking or writing about them, they are named by the term commonly employed to designate them in their present state. This is the case with the term granite, used for the combination of feldspar, quartz and either or both hornblende and mica. This combination occurs in the basalts*, andesites and trachytes largely through the formation of secondary quartz and orthoclase, but appears to be largely original in some of the trachytes and in the rhyolites. All these are called granites without regard to the question of their origin, but in a systematic labeling or classification they would be placed under the types of which they are the alteration forms, if that could be ascertained.

The term zirkelite was used in 1887 to designate the altered basaltic glasses, in distinction from their unaltered or tachylitic state.

Melaphyr and epidosite appear generally to be altered basalts, but some altered andesites have been given these names which are therefore placed under both species.

The chief portion of the syenites, minettes and phonolities belong under the andesites, although rocks belonging to other types have been so named. Granulite appears to be chiefly a rhyolitic ash, and thus mainly belongs under that type or species; although some of the forms are apparently non-fragmental, and others apparently are basalts or some species other than rhyolite.

The term shastalite (from Mt. Shasta) is here used to designate the unaltered glassy forms of andesite, and the name weiselbergite for the altered forms.

In the same way lassenite (from Lassen's Peak) is employed for the unaltered glassy trachytes, and metabolite (metabolé) for the altered glassy forms. Obsidian is here used for all glassy forms of rhyolite including pumice, pitchstone, pearlite, and spherulite, while the term felsite would appear to cover the altered states both of obsidian and rhyolite proper. Much of the quartz in the felsites or quartz porphyries appears to be a secondary or alteration product which in the process of crystallization has included, partially or entirely, portions of the groundmass, giving to these secondary quartzes a structure closely like that belonging to the primary forms.

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* Peridotites, Gabbros, Diabases, and Andesites of Minnesota. 1887, pp. 46, 50, 52, 59, 67, 75, 81, 82, 85, 86, 96 and 97 and plate IX.

The term jaspilite was given in 1880 to the reddish, whitish and greenish rock associated with the iron ores of the Marquette District. This rock has ordinarily been called jasper, but it is in no sense a true jasper, and that name is not a proper term for it. Neither is it in any sense a schist, except in some of its abnormal forms, although that name has been used for it to some extent. At the time the name jaspilite was first employed. the rock was considered to be of eruptive origin, but, as discussed later in this paper, that is now an open question.

The term jaspilite is at present in current use and will be employed for the rock, whether it shall be found to be eruptive or sedimentary.

(*j*) In the sedimentary rocks, mechanical and chemical (including organic), the question of structure, consolidation and mineralogical or chemical composition has entered largely into the nomenclature of the past, as all of these physical characters are more or less manifest in the rocks. As in the eruptive rocks, so here, no hard and fast lines separate the different varieties, but they pass one into the other, and the names are employed as far as possible in connection with their common or general use.

The term laxite (laxus) is used here as the specific or family term for all the fragmental or mechanically formed rocks,* and in their classification the effort is to pass from their unconsolidated towards their most altered stage. As most mechanical rocks originally came from the debris of eruptive forms, the same alteration would naturally be expected to occur in the detritus that occurs in the non-fragmental forms. Further, similar rocks would be expected to result. Where therefore, the origin is known, the detrital forms are placed, in the classification, under the general head of the eruptive rock type from which they are derived, but when unknown are placed under the laxite type. In speaking of them, however, no different name would be used, as a gneiss or a schist would be called gneiss or schist, no matter what its derivation might be. The term merolite was employed in 1884 to designate the various pseudo-breccias so common in serpentines, limestones, veinstones, etc.

Limestone is placed both under the chemical (including organic) and under the fragmental forms, since both modes of occurrence exist.

Sinterite is used for the siliceous sinter of quartz, fiorite for the opal sinter, and millite for the freshwater quartz so commonly used for buhrstones. The other terms from their association or common use will readily explain themselves. Some other minerals occur in beds of sufficient size to be classed as rocks, but it would seem that all the principal ones had been given. Corundum, besides its emery beds, also forms a very tough, coarse crystalline rock, containing mica, that is found in Georgia.

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* It is, however, mainly used as a collective term for the unconsolidated forms, like mud, sand, gravel, shingle, etc.

CHAPTER III.

THE CASCADE FORMATION, OR THE OLDEST SEDIMENTARY AND ERUPTIVE ROCKS.

§ 1. The location in which the relations of these rocks to the younger formations have been best made out by the State Geological Survey is in the Cascade range, in the vicinity of the Volunteer mine. Here one finds an old hornblendic schist that has been invaded by eruptive granite and other volcanic rocks. This formation is especially marked to the southeast of the mine, and rises in abrupt but low hills near the stream which flows southerly into the Escanaba. It is not impossible that the hornblendic schist may be an altered eruptive, or volcanic rock, instead of being a sedimentary one, although the evidence thus far obtained points to the latter origin.

Nearer the mine one finds a sedimentary rock lying on the oldest schists and granite, and composed of their debris. This is especially marked in the vicinity of the stream. Some of the boulders that make up the base of this detrital deposit are several feet in diameter, the rock passing from a coarse conglomerate into a fine schist apparently composed of granitic mud. This forms the base of the Republic formation which here clearly reposes uncomformably on the Cascade, while in the near vicinity the basement conglomerate of the Holyoke formation, composed of the debris of the Republic and Cascade formations, can plainly be seen reposing unconformably on the Republic.

In the Cascade formation occurs much gneiss which has been traversed by numerous basic, as well as by acidic dikes, the latter mainly having the character of granites or allied rocks, and being frequently quite schistose. The basic rocks are essentially diabases, diorites and schistose modifications of these or allied forms. Part of these eruptive rocks, both granites and diabases, are evidently younger than the Republic formation, if not in some cases younger than the Holyoke. The Cascade formation, geologically and petrographically, is very interesting and should have careful and accurate investigation. As yet but little study has been given to it by the State Survey, owing to its minor economic importance compared with that of the Republic and other subsequent formations. So far as studied by the Survey, the chief economic value of this formation rests upon its building stones, its timber, its valleys for agriculture, its clays and sands, its bog ore deposits and its mineral veins.

A marked exception can be made to this statement, if, as I have supposed, it can be proved that the fundamental Ishpeming and Negaunee iron ore deposits belong to the Cascade rather than to the subsequent Republic formation. Under the head of this latter formation and in the discussion of the iron ores this subject will be much more fully treated.

§ 2. The Cascade formation may at the present time be roughly considered to be composed of the following groups of rocks, commencing with the oldest:

1st. Gneissoid granites or gneisses.
2d. Gneisses.
3d. Basic eruptives and schists.
4th. Jaspilites and associated iron ores.
5th. Granites.

Up to the present time so little study has been made of this formation, that the above can be considered only as a mere hypothesis, the correctness of which is liable to be called in question at any moment by the discovery of new evidence; while it is very probable that the fourth group will be found to belong to the Republic formation.

§ 3. The investigations of the Survey show that a part, at least, of the Cascade formation is composed of detrital materials derived either from an older formation or from some eruptive or volcanic source. It also appears probable, from what is now known, that the Cascade formation will prove to be composed of two or more distinct geological formations. Some evidence of an older formation was obtained in the Huron mountain region, where the chief rock, as shown by the observations of Mr. Seaman and other officers of the Survey, appears to be a gneissoid granite rather than a true sedimentary gneiss, although it may finally be proved to be the latter, as it has a well marked foliated structure. For convenience we will call rocks of this kind gneissoid granites. During the past summer this rock was studied in the region in the immediate vicinity of the Huron Bay & Iron Range R. R. Here the foliated structure of the rocks, and the mineralogical differences in the alternating bands are very striking. The foliated minerals observed in this rock are mica, hornblende and chlorite, which give a dark gray to black color to the parts of the rock in which they predominate. The lighter colored bands are composed mostly of feldspar and quartz, with a few scales of disseminated brown mica. In part of the rocks of this area the contained feldspar is mainly plagioclase, as may be seen by the twin striae.

There is one feature about these gneissoid rocks that suggests for them a different mode of origin from that of the rocks that I call gneisses. Those parts of the gneissoid rock that seem to be least altered, or nearest to their normal condition, are dark grayish, foliated, and composed principally of crystals of hornblende, with plagioclase feldspar, and usually some quartz.

In such places the structure is less marked, but on approaching any lines of fracture, such as those produced by eruptive rocks, the hornblende is replaced by chlorite, or in places by a black or brown mica. This altered form usually contains a considerably larger proportion of quartz than the unaltered form. The rocks, therefore, may not unjustly be considered as an altered form of a somewhat basic or syenitic type of eruptive rock, in which the foliation is due to flowing, to pressure, or to chemical action and heat, although it is possible that one or more of these agents may have been wanting. The rocks above considered must not be confounded with true sedimentary gneisses that flank this and other areas of the Cascade formation.

§4. The gneisses last mentioned are apparently of a younger age than the preceding gneissoid granites, and they are clearly of a fragmental origin. At the localities in which they best show this they contain fragments that closely resemble the above mentioned gneissoid granites of the Huron Bay region, from the debris of which the true gneisses are apparently derived. If this is the case, and if the above gneissoid granites are truly metamorphosed eruptive rocks, and not true gneisses, then the fact that the gneisses contain debris of the former proves only that the gneisses are younger in order of time, but not of necessity of younger geological age. They may or may not be; proof is still wanting. If, on the other hand, the rocks above called gneissoid granites are true gneisses, or metamorphosed sedimentary rocks, then it is clear that the other gneisses are of a later geological age, and the Cascade Formation should be divided. Similar gneisses with gneissoid fragments occur in various places in the Cascade formation in the Menominee and other regions.

§ 5. In the Huron Bay, Menominee and other regions, the Cascade formation contains true granites, which hold an intrusive relation to the gneisses and other foliated rocks, although there are some quite large masses of granite whose relation to the surrounding rocks can only be surmised. The greater portion of the apparently true granite is of a gray color, except when it is cut by some of the later diabase dikes. In this case it is often of a brick red color. The same color is often given to the gneisses when they are penetrated by the same dikes. Among the granite dikes the older system has generally an east and west course, while it is seen to be cut, in its turn, by a system that has a north and south course. Dikes of granite have been observed in the bluff northwest of the Boston mine, and at various places in the gneiss in the area north and northwest of that point. In the vicinity of Marquette, on Sec. 10, T. 48, R. 25 W., a red granite dike cuts a gray granite, and both of these are cut by diabase dikes.

(*a*) In the Menominee region, especially in the Felch Mountain district, these granite dikes are well exposed. Here they are seen not only to cut the gneiss, but to penetrate the Republic or iron formation. Mr. Wright, in 1885, pointed out one of these dikes cutting the iron series near the Metropolitan Mine, on Sec. 32, T. 42, R. 28 W., and in the summer of 1887 Mr. Seaman made figures to illustrate the occurrence of the granite dikes which cut through the quartzite on section 12, T. 41, R. 30 W. These dikes bear north about 35° west. During the past season this place was revisited by Mr. Seaman, accompanied by myself, and on Sec. 12, T. 41, R. 30, these or similar dikes were also found to the southeast of the locality of which the figures were made. At this place these dikes were seen to cut northwesterly through the adjacent gneisses. Another granite dike, striking about N. 65° E., was found to cut obliquely across the foliation of the gneiss, and to be itself cut by one of the granite dikes that have the northwesterly course. On the Cascade Range, also, granites have been seen to cut the gneiss. It would then appear, that, whether the basement upon which the gneiss was deposited was a granite or not, this gneiss has been subsequently cut by two different intrusions of granite, as well as by numerous reticulating basic dikes. The older granite dikes are cut by quartz veins, and some quartz veins are cut by the younger dikes, but the identity of the two sets of veins could not be established.

(*b*) In the same region a basic dike, now altered to an amphibole schist, was found intrusive in the gneiss, but it was cut, in its turn, by the granite dikes, which also enclosed mica schist, although in some cases the latter was in dike-like forms, that may be altered basic dikes and not inclusions of a sedimentary schist. This is a point that needs further investigation.

On Sec. 2, T. 40, R. 30 W., a basic dike, now an amphibole schist, similar to that above mentioned, was seen to be intrusive in the quartzite, and in its turn to be cut by a felsite dike.

The older of the granitoid dikes above mentioned may not improbably have its equivalent in the felsite dikes so well known in the chlorite and amphibole schist area, in the vicinity of Marquette. In the latter place, the amphibole schists are cut by numerous felsitic or quartz porphyry dikes, which, as a general rule, closely follow the foliation. Usually, when the dikes are of considerable width, they have a distinctly granitic structure, in places forming true granites of fine or medium grain.

Dikes of a rock closely resembling a hornblende schist or gneiss are found on the northwest shore of Partridge Island, on Gull Islands and elsewhere, cutting the granite.

In the Cascade Range, Sec. 31, T. 47, R. 26 W., dikes of hornblende schist or gneiss cut the country rock or gneiss of the region. These dikes, in their turn, are cut by others containing altered porphyritic crystals of feldspar (saussurite), while both are cut by a gray granite. This, in its turn, is cut by a red granite, which also crosses some diorite dikes, whose relation to the schist dikes is not at present known. The granite was also observed to cut diorite rocks on Sec. 35 and Sec. 36, T. 48, R. 28 W., and Sec. 1, T. 41, R. 30 W.

CHAPTER IV.

THE REPUBLIC FORMATION.

§ 1. This formation is composed of various rocks, which it is more convenient to take up separately and as near as possible in the order of their age. These rocks may roughly be divided as follows, commencing with the oldest:

1st. Conglomerate, breccia and conglomeratic schist.
2d. Quartzite.
3d. Dolomite.
4th. Jaspilite and its associated iron ores.
5th. Argillite and schist.
6th. Granite and felsite.
7th. Diabase, diorite and porodite.
8th. Porphyrite.

Conglomerate, Breccia and Conglomeratic Schist.

§2. As pointed out in the discussion of the Cascade formation, there is found at the base of the Republic formation a series of conglomerates and conglomeratic schists which passes into a talcose or hydrous mica schist (sericite schist). These conglomerates and schists, in the vicinity of Palmer, contain large boulders of the underlying granite as well as fine fragments and debris of the various underlying diorites, gneisses, schists, veinstones, etc. The finding, in the overlying conglomerate, of these rounded and water-worn fragments of the veins that cut the Cascade formation, is taken as conclusive proof that the Cascade formation is the remnant of an old dry land region, upon whose shores the debris constituting the Republic formation was laid down.

One of the best points in the vicinity from which to observe the succession is on Sec. 32, T. 47, R. 26 W., about 1,850 paces N. and 1,250 to 1,500 paces W. of the S. E. corner. Here one can see the coarse conglomerate resting on the gneisses to the south and overlain to the north by quartzite, fragmental jaspilite and quartz schist. The dip is about 40,° with a strike north 70° W. The conglomerate here contains numerous pebbles of gneiss, as well as some of granite, diorite, schist, and of quartz veinstones. It was observed that nearly all these pebbles (except the quartz) were charged with numerous tabular chloritoid crystals.

Quartzite.

§ 3. In the vicinity of the Volunteer mine, quartzite of a whitish color was observed immediately overlying the basal conglomerate, and in some other localities it reposes directly on the Cascade formation. This quartzite has not been fully made out in its relations, as it is of minor thickness compared with the quartzites of the Holyoke formation, for which it is generally mistaken. In some of the explorations of the Cleveland and Iron Cliffs Mining Co., the chief Mining Engineer, Mr. A. S. Parnall, reports that a quartzite has been found underlying their ore formations. This is apparently the lower, or the Republic quartzite above mentioned. As an assistance in exploring and mining, the exposures of this quartzite should be carefully located and mapped at as early a date as practicable.

More or less quartzite of a ferruginous nature is found associated with most of the iron ores of the Republic formation as an interbanded and contemporaneous deposit.

(*a*) The heavy quartzite which extends in the Menominee district from Sturgeon river along Pine river, and with one intervening break to Metropolitan, is thought to belong to the base of the Republic formation, as it is found in various places close to the Cascade gneiss and granite, dipping away from that formation, and, as before stated, is cut by dikes of the granite, on Sec. 12, T. 41, R. 30 W. This quartzite is probably Republic, if the overlying iron ores are Republic, which they are here considered to be, although no direct proof has as yet been obtained. The ground for this belief rests chiefly on the physical character of the ore formation.

Dolomite.

§ 4. One of the interesting rocks of the iron series is a dolomite. It appears to be best developed in the Republic formation, to which it is now provisionally referred, and occupies there a low horizon, either interbedded with the quartzite, or occupying its place. In color the dolomite varies from white, through flesh red and light gray, to quite a dark bluish gray. It is often quite siliceous, either from the mechanical or more probably chemical admixture of siliceous material. The economic value of this rock is perhaps not so much an inherent quality as it is an associative one, for its relation to the iron-bearing rocks has long been a guide to the explorer in certain districts. Whether any of the stone will ever be used for ornamental purposes, is a problem of the future. So far as color is concerned, some of the flesh red and variegated varieties would make a handsome stone for interior purposes. Owing to its contained silica, the stone would be very expensive to work and polish, and it is probable that its polish would be uneven and irregular.

The dolomite is generally jointed so much that the blocks are small, but as this is usual with limestone, it is possible that excavations in depth might here as elsewhere develop a less jointed rock. The great amount of folding and pressure to which most of the rocks of this region have been exposed, renders it likely, however, that the jointing would be developed throughout the dolomite to an injurious extent.

The dolomitic rocks are best developed in the Felch Mountain region and northwesterly from there to Fence river, in T. 45, R. 31 W. They seem to flank the gneiss areas in the region north and west of Felch Mountain much as the quartzite does along the valley of Pine river.

In the S. part of T. 42, R. 28 and R. 29 N., the dolomite is often tremolitic, while crystals of malacolite (?) are not uncommon. In the northern parts of those townships the rock is more evenly grained and is sometimes of the flesh-red variety, as is also that occurring along the Michigamme a short distance below its confluence with the Fence river, in T. 44, R. 31. Dolomite also outcrops in the Fence river near the forks. At Metropolitan some of the purer portions of the dolomite were kiln-burnt, and it is said to have made a fair lime.

The dolomites of the Menominee district have been quite fully described by Brooks and Rominger in volumes I and IV of the Survey reports, and need not be taken up here.

Jaspilite and its Associated Iron Ore.

§ 5. Associated with the various eruptive and detrital rocks are the immense bodies of iron ore, or ore and jaspilite in the Marquette, Menominee and Gogebic districts. The relations of the ore and jaspilite to each other, and to their associated quartzites and eruptive schists, are matters of very great economic and scientific importance, to which, therefore, much attention has been paid. From the absence of evidence or proof in the writings of the most of those who have discussed the origin of the ore and its relations, one not unnaturally concludes, that most of the opinions advanced have been based on preconceived ideas, rather than upon a thorough study of the rocks in place and conclusions drawn from the evidence they present. This latter method of investigation, which the writer deems the only correct one and which has been the one he has endeavored to follow in all his work, has also been followed by some other geologists, and it has thus far led to very different conclusions amonst them. This difference of opinion arises from various causes, some of the chief of which are that the observers see different facts, as well as draw different conclusions from the same facts. Some of the different views will be given below, commencing with the view that the jaspilites are of eruptive origin.

(*a*) If we return to the unconsolidated or only partially consolidated detrital rocks that existed as sea deposits in the primitive days, we find that these rocks were apparently invaded by eruptive material which forced its way irregularly through the soft sedimentary materials, indurated them, bent their planes of deposition, changed their color, and sent tongues, arms and dikes through them in every direction. It has also protruded through the schists in large masses, contorting them and tearing them across, and oftentimes ending in small arms or branches. This eruptive rock is now very greatly metamorphosed, and is termed jaspilite. Like the eruptive siliceous rhyolites and felsites, it is generally more or less banded in its character, which banding is due apparently to its having flowed, a phenomenon that has its counterpart in the banding of the siliceous furnace slags, such as one may see about iron furnaces. It is this fluidal structure or banding that is so often mistaken in the rhyolites, felsites and trachytes for planes of sedimentation.

(*b*) It is a well known fact that all of the eruptive rocks contain iron in the form of magnetite and hematite in greater or less abundance, and some contain iron in its metallic state. The latter is the case with some basaltic dikes in Greenland, which hold not only finely divided magnetite and metallic iron throughout the entire mass, but also contain immense blocks of metallic iron imbedded in them. So, too, the old, coarsely crystalline eruptive basalts known as gabbros contain, about Duluth and elsewhere in Minnesota, so much iron ore that they have been worked for it, and the only drawback to their successful working is the fact that the iron contains titanium. As observed by Whitney, were iron ore as valuable as native copper, there is not a dike or lava flow of any size that it would not pay to work; and were iron ore as valuable as silver, no eruptive rock now exists on the face of the globe that would not be actively prospected. The question is merely one of value and amount. In the same way we find iron ore associated with the jaspilites to a greater or less extent. In some places the ore is locally concentrated with little or no jaspilite; in others the jaspilite predominates and forms a lean ore not suitable for working. The concentration of the ore, in bodies sufficiently rich to be worked, is very irregular, but the ore is said to be generally in lenses connected by the intervening leaner portions of jaspilite, the amount of the workable portion varying, of course, with the varying price of ore.

(*c*) The jaspilite, with its associated ore, is found to have been subsequently broken or jointed, and the cracks filled in with iron ore, apparently through the action of the percolating waters which have chemically affected both the jaspilite and its ore, and brought about great changes in both. Further, we find that the jaspilite and its ore have been broken up and worn away by the ancient waters, and deposited as mud, sand and shingle upon the underlying ore deposits. This detrital, or sedimentary, material has become consolidated, and forms true sedimentary deposits of iron ore, which in many places are apt to be lean. These deposits have to a greater or less extent, been worked for their ore.

(*d*) Wherever the intrusive masses of the jaspilite have come in contact with the schists the latter have been impregnated with iron to a greater or less extent, and these impregnations are sometimes mined.

The iron ore that belongs with the jaspilite is mainly of two mineral species. magnetite, and hematite with its martite variety.

The hematite frequently occurs in thin layers in the jaspilite, and in irregular masses in the schists. Microscopic sections of these forms that the writer has examined show that the supposed hematite here does not occur in the form of hematite, but in the form of magnetite, hence was a martite instead of a hematite proper. It has been suggested by Brooks and Credner that all the Lake Superior ore was once magnetite, a view that has many facts to support it.

(*e*) If one chooses to observe carefully the relation of the jaspilite to the schists in the mines, he will see that the former with its associated ore oftentimes irregularly branches or cuts through the schists (or soap rocks of the miners). This irregular branching character of the jaspilite is in full accord with the view that it is eruptive in its origin, which explains why it cuts across the foliation or platy structure of the schist. This leaves the latter rock with little support, and with the sharp edges of the joints pointing downward. To this cause is due part of the great insecurity of the hanging walls of schist and the danger to the miners working beneath.

The question of the eruptive origin of the jaspilite and its associated iron ore is one of great economic and scientific interest. Their eruptive origin was in 1850 advocated by Foster and Whitney, but the view taken by these investigators was considered by subsequent observers to be incorrect and the structure of the jaspilite explained by sedimentation, *i. e.*, that the iron ore was originally a bog iron, or limonite, which had subsequently been metamorphosed. In 1879 the present writer collected sufficient facts in the Marquette district then to prove, to him at least, that the sedimentary view that held to the bog iron origin of the ores, and to the interstratification of the jaspilite and schist, was untenable, and that with our then knowledge, the eruptive origin of jaspilite and its associated iron ore, with their subsequent chemical alteration by percolating waters, was the only view that would explain the phenomena, as he then saw and figured them, unless it could be shown that the associated schist itself was eruptive. The latter hypothesis the writer then examined into, but found no evidence to sustain it, and so it was dropped.

One difficulty in the way of then proving the schist eruptive was that I considered all the schists in the immediate vicinity of the ore as having the same origin, and part of the schists were seen to be distinctly fragmental and conglomeratic. This evidence naturally was considered as conclusive for all the schists and argillites, although at that time the writer was in advance of his contemporaries in claiming that which none believed then, but which is generally supported now, that rocks that can be and would be called chlorite and hornblende schists, argillites, etc., are the direct products of the alteration of eruptive rocks.§

(*f*) The writer's view, that the ore and jaspilite were eruptive, was later endorsed by Selwyn, Director of the Geological Survey of Canada. More recently an attempt was made by Irving* to explain the origin of the ore as a carbonate, but he, as well as nearly all the more recent advocates of sedimentation, began by either denying or belittling the occurrence of the very facts that the present writer has figured, and that had caused him to hold the eruptive view. In this Irving was much in error, as the observations of his own Survey have since demonstrated that eruptive phenomena occur on a large scale between the schist and the jaspilite. Any theory of the origin of the iron ores that starts out with a denial of the facts that it ought to explain, can hardly be accepted until it recognizes those facts and explains them. When this is done, and all the facts of the ore deposits collected, we may hope for some common ground of agreement, which will serve as a guide in exploring for and in mining the ores. In accordance with this method of studying the ores and associated jaspilite, N. H. Winchell, in his discussion of the iron ore of the Vermillion district, in his report for 1886, admits the occurrence of the eruptive phenomena, but explains them as due to sedimentary and chemical action. instead of being due to eruptive causes. The late State Geologist of Michigan, Mr. Charles E. Wright, had, as early as 1885, come to the conclusion that the only satisfactory explanation of part of the phenomena of the iron ores was that they were eruptive, and it must be admitted that no geologist in America was more familiar with the iron ore deposits of Michigan than he. It is the source of the deepest regret that he could not have lived to publish his evidence and conclusions.

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§Proc. Bost. Soc. Nat. Hist., 1877, XIX., 236, 237. Bull. Mus. Comp. Zool., V., 275-287; 1880, VII., 42, 43, 45, 46, 48, 69, 70; See also Sketch of the Geology of the Marquette and Keweenawan Districts, 1st Ed. 1890, 2nd Ed. 1891.

*Am. Jour. Sci. 1886 (3), XXXII., 256.

The writer based his conclusions that the ores were eruptive on the fact that the jaspilite and ore form dikes and intrusions in the associated sandstones and schists, inclosing fragments or "horses" of the schist; on their twisting, bending and indurating the schist, filling it with crystals of the ore; on their breaking in every direction across the foliation of the schist, as well as with it; on their pronged structure; on the former magnetite condition of the iron ore; and, as suggested by Whitney, on the great mass and purity of the ore, which is beyond that of any known, more modern sedimentary deposit.

One fact that has an important bearing on this is, that it is reported that the ore is never isolated in the schist, but is always connected with the jaspilite in the regions in which the eruptive phenomena exist, and while that jaspilite may end in one direction like any dike, it has never been known, so far as the writer can ascertain, to end in another direction, unless cut by a fault or by later eruptive rocks. So long, then, as the jaspilite can be followed, there is a prospect of obtaining good ore somewhere along its continuation. The irregular occurrence of the ore and its jaspilite, especially in its being found in the most unexpected places, thrust through the schist, is another strong evidence of its eruptive origin.

(*g*) One of the economic aspects of the question is as follows: If the ore is sedimentary, it must follow the laws of sedimentation and be worked out the same as a coal bed, but if of eruptive origin its future is unlimited, except by the difficulties of deep mining, or because of its being cut out by the diabase and diorite, or some other eruptive rock. If the view of Foster, Selwyn, Whitney, Wright and myself is correct it means far more for the future permanence and success of the iron mining industry of Michigan than do any of the other views that have been suggested. This fact must not, however, influence our decision, which must be based purely on the evidence and its interpretation.

(*h*) The apparently intrusive relation of the jaspilite to the schist can be seen in the railroad cuttings southeast of the Marquette depot, where the writer discovered jaspilite dikes in 1888. Similar dikes can be seen on a hill west of the sandstone quarry, south of Marquette. The jaspilite here contains fragments of schist, but it is not impossible that all these dikes may be explained as veins. Evidence of the eruptive origin of the ores and jaspilite can also be observed in most of the old workings about the Jackson, Cleveland, Lake Superior and various other mines about Negaunee and Ishpeming, although they are not as plainly marked now as when the workings were new, because of the weathering, the filling in of debris, etc., or else are entirely obliterated from these causes. Every figure drawn by the writer in 1879 was taken from actual observed occurrences that could be seen then by any close observer. The entire region from Marquette to Michigamme is full of interest at every point, and nowhere can a student or geologist stop without finding problems worthy of his attention.

(*i*) The jaspilite is well exposed in ridges to the southeast of the Jackson mine and elsewhere about it. It is the "hard ores" and jaspilite about Ishpeming and Negaunee that, at present, I would refer to an eruptive origin, although there are other localities in which the same intrusive relations have been observed. It is, however, quite probable from evidence more recently found by the State Survey and the

United States Survey, that I shall have to abandon entirely the view that any of the ore and jaspilite is eruptive. This is the finding of dikes of schist or argillite cutting the ore deposits both in the Republic and Holyoke formations, a fact that explains many of the intrusive or eruptive phenomena observed, which the present writer was the first observer to figure and to call into notice. With the explanation of the main phenomena, given by these schists, many other points can also be explained by the crushing, faulting, and squeezing these rocks have undergone through the action of the eruptive granites, diorites and diabases, as well as by the subsequent chemical action. Twelve years ago the writer stated concerning the jaspilite and ore, that he was "perfectly willing to accept any theory that will explain the facts observed," [*] and this he now does.

The difficulties encountered in the study of the ore formation have in part arisen from the fact that the present writer commenced his work in the most difficult region, while the United States geologists [†] approached it through Wisconsin and the Gogebic district, where the structure is simple (comparatively speaking), and where dikes of a well marked type occur abundantly.

However, the United States geologists appear also to have their difficulties, inasmuch as seemingly they likewise have spread their eruptive schists and carbonate ores over more territory than it appears possible could belong to them. There would seem to be as much danger in an easy as in a difficult approach to any subject.

The above mentioned eruptive argillite, or schist, is best seen in dykes in the Saginaw, Goodrich and Fitch mines where it cuts both the Republic and the Holyoke formations, and at the Winthrop mine where it was seen to cut only the Republic.

Other dikes of this rock were seen at the Cyclops, Norway and Paint River mines. Another dike that does have an extended exposure can be seen in the Jackson mine, but at the time of my former observations (1879) it was seen only at one end at an obscure point. None of the other above mentioned localities were seen by me at that time. In the light of the above observations other dikes or probable dikes can now be observed about Negaunee and Ishpeming. The first publicly to call attention to these dikes appears to be Prof. C. R. Van Hise of the United States Geological Survey, [‡] but it does not appear that he observed that they cut the Holyoke formation, and furthermore he has apparently placed with the truly eruptive schists many that are sedimentary.

In a paper published while this manuscript was in preparation and after the above was written, Van Hise points out that the schist dikes cut the overlying quartzite, while he makes it more and more evident that with these he has united much sedimentary and even conglomeratic schist, that he considers a modified diorite. In fact, the obscurity of the region appears to be largely due to the occurrence of these eruptive and sedimentary schists and argillites which are closely alike in physical characters and yet as dissimilar in origin. Part of this resemblance may be due to the sedimentary rock having been partially or entirely formed from a tufa of the same composition as the dikes, as is found to be apparently the case in the Gogebic district. The dikes that occur in association with the iron ores of an argillitic or schistose character appear to me to belong to the acidic rocks, probably felsites, as they show many points of similarity to some of the altered felsite dikes that cut the Republic formation, outside the region of the mines. If these dikes are more basic than the felsites, they more probably belong to the porphyrites than to the diabases and diorites, since the latter commonly present different alteration characters in localities where they have been recognized as old basaltic rocks. It is of course not denied that some of the dikes associated with the ore are modified diorites, for many diorites and diabases, one melaphyr and several dikes of schist were pointed out as cutting the iron series, as observed by the writer in 1879.*

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[*] Proc. Bost. Soc. Nat. Hist., 1880, XX., 479.

[†] Irving, Am. Jour. Sci., 1886, (3), XXXII., 256.

[§] Am. Journal of Science, 1889, (3), XXXVII, 47.

§ 6. With the above explanations which may account for all the eruptive phenomena observed by the writer, attention will now be given to the observations of the Survey bearing upon the sedimentary origin of jaspilite and associated ore deposits belonging strictly to the Republic formation.

On Sec. 32, T. 47, R. 26 N., in the vicinity of Palmer, overlying the before mentioned basal conglomerates and quartzite, is a series of beds composed of interbanded fragmental jaspilite, ore, and ferruginous quartzite, the latter usually in thin and minor bands. In this there were observed and collected rounded and water-worn fragments of the banded jaspilite that showed that the banding was prior to the deposition in the Republic formation. These fragments stand at every angle in the rock, with the banding, as usual, extending in their longest direction. A secondary banding, apparently of chemical origin, was observed in part of the jaspilite pebbles. Most of the interlaminated bands of jaspilitic material, associated with the more coarsely fragmental jaspilite and quartzite, appear to be composed of a fine jaspilite mud derived from the jaspilitic debris.

The fragmental jaspilite shows from its banding that it apparently was derived from the debris of some pre-existing rock similar to that observed at Ishpeming and Negaunee. So far as I have studied the fundamental jaspilite and ore at Ishpeming and Negaunee, I have not been able to find in them evidences of sedimentary origin; for banding is not the slightest proof of such an origin, as any one familiar with the modern eruptive rhyolites and the old felsites is well aware.

The evidences of sedimentary origin are abundant in a large portion of the jaspilite and ore of the Republic formation, but the study of years has failed to reveal any such evidence to me in the Negaunee and Ishpeming jaspilite, although the associated argillite and schist are in part, at least, clearly sedimentary. This lack of evidence may be due to the silt having been finer, and deposited in a deeper sea, but it certainly seems strange that it has not been found heretofore. This formation would have been restudied in the fall of 1891, in the light of observations made elsewhere, had it not been that the early snows prevented. So far as the survey work has gone, the fundamental ore and jaspilite of Ishpeming and Negaunee appear stratigraphically to belong to the Republic formation, but this evidence I do not accept as conclusive, since similar stratigraphical evidence could be used in connection with the relations of the Cascade and Holyoke formations to prove that there was no Republic formation, if it were not that in this latter case further evidence exists, which is wanting in the former. The stratigraphical evidence is mainly as follows:

At the Volunteer mine the Republic formation bends to the north and west, and apparently was once connected by way of the Foster mine with the Winthrop, where it bends north. This connection has, however, been cut by the diorite in various places. Near Negaunee the diorite was also found cutting the iron-bearing strata apparently belonging to the Republic formation. This is near the line between Secs. 18 and 19, T. 47, R. 26. The Republic formation apparently extends from near the Volunteer through to the South Jackson mine, crossing Secs. 30, 19, 18, 7 and 6. It is, however, possible that the formation observed on 19 and 30 belongs to the upper, or Holyoke series. Further evidence is the resting of the Holyoke conglomerate on the iron-bearing rocks at Ishpeming and Negaunee. The strongest evidence that the jaspilite at Ishpeming and Negaunee is of Republic age is the similar rock associations which the jaspilite here has with the jaspilite known to belong to the Republic formation. The simplest explanation of the ore formations as they now exist is that there is an orginal one belonging to the Cascade formation, from which the jaspilite and ore of the Republic were derived, and this working hypothesis is one that ought to be carefully investigated.

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* Notes on the Geology of the Iron and Copper Districts of Lake Superior, pp. 43-46.

(*a*) It is possible that the fragments of jaspilite may be proved to have been derived from clayey masses, as mentioned under the Potsdam sandstone, or from the quartz veins of the underlying Cascade formation. Fragments of those veins are to be found associated with the jaspilite fragments in the underlying conglomerate, but they do not, where they are known to be from the veins, approach the jaspilite in physical characteristics, even if they do in color. It seems strange that when the overlying and underlying detrital formations should have their origin so well marked, this special jaspilite should have lost every trace of its origin.*

Again, there ought to be numerous veins in the underlying Cascade formation of the color and structure of the jaspilite, if the latter is vein material, in order to account for the great thickness of the detrital jaspilite in the Republic formation.

This is not the case, as the vein matter is a whitish and distinct vein quartz, while the jaspilite is usually red and shows no vein structure except that produced by subsequent chemical action. The working hypothesis that the jaspilite is derived from the veins is also one that needs thorough and careful investigation.

(*b*) One element that has prevented the water-worn fragmental character of the jaspilite from being more readily recognized, is that very much of the angular and even rounded fragmental jaspilite in the Republic formation is of a brecciated origin due to the crushing and faulting of the layers that are composed of the fine jaspilite mud before mentioned. This brecciated structure is apparently due to the crushing produced by the later eruptive action and earth movements which have been so common in this old land.

(*c*) Fragments of the iron ore and a fine mud of the same appear to have been deposited with the detrital jaspilite in the Republic formation. That the fragments of ore have not been more commonly recognized is due to the subsequent chemical action and the ready solubility of the ore, so that in most cases only the matrix, or a rusty mass, is left. If the jaspilite is derived from the veins of the Cascade formation, then the ore must in general have been derived from the gneiss, granite, schist and basic eruptives associated together in the adjacent Cascade formation, i. e., deposited in like manner as the magnetic sands now are on the shores of Lake Superior.

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*Irving, Am. Journal of Science, 1886, (3) xxxii, 258.

That the original jaspilite and ore of the Republic formation are of a detrital origin; that they were originally conglomerates, breccias, sands and muds; and that they have subsequently been chemically acted upon by percolating waters, as was long ago pointed out by the present writer,* the evidence collected by the Survey would seem clearly to prove.

§ 7. In this connection it is best to take up more carefully the conglomerates observed above and below the ores of the Republic formation, and some of the views concerning their bearing and the geological subdivisions they have been supposed to indicate.

(*a*) One of these conglomerates belonging to the Holyoke formation, on T. 47, R. 26, was described by Foster and Whitney as follows:†

"On the line between sections 29 and 32 is a remarkable knob of conglomerate, alike interesting from the fact that such a form of rock is of rare occurrence among the Azoic series of this district, and from its intimate connection with the origin of the masses of iron in its vicinity. The conglomerate forms here an isolated, rounded elevation rising at least a hundred feet above the general level. It is made up of coarse blocks of various sorts which belong to the neighboring trappean and slaty beds, and are of very considerable dimensions. Among them we recognized not only fragments of the rock associated with iron, but masses of the iron itself, and of the banded and jaspery varieties. Most of the fragments of this remarkable breccia are but slightly rounded and worn on their edges, having in this respect much more the appearance of a friction conglomerate than of one in which the long continued action of water had played a part. The blocks are cemented together by a very hard ferruginous paste. The nature of the surrounding country, covered with soil and forest trees, prevented us from satisfactorily tracing its connection with the adjoining rocks. We are inclined, however, to regard it as connected with the eruption of the adjacent granite, and rather as the effect of the crushing and elevating forces which such an elevation must have called into play. If this is the case, it may be considered as analogous in its mode of formation to the conglomerates of Keweenaw Point. A fact worthy of notice in this connection is, that in spite of the heterogeneous structure of the mass, it exhibits a distinct tendency to separate, or flake off, in thick concentric layers, like some eruptive granites.

The nature of the fragments composing this breccia, and of the cement by which they are united, proves conclusively that the process of formation of the ores of iron, and the impregnation of the slaty rocks with metallic matter, must have been one of long continuance, and not a merely momentary operation. The various kinds of ore must have been in existence before the formation of this mass, but they were subsequently broken off and mingled together in confusion. Emanations of metallic matter must still have been issuing from beneath, since we find the whole deposit thoroughly impregnated with it, and converted into one firmly coherent mass."

(*b*) The conglomerate at the base of the Holyoke at Republic, Secs. 6

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*Notes on the Geology of the Iron and Copper Districts of Lake Superior. 1880, p. 34.

†Report on the Geology of the Lake Superior Land District. 1851, II., pp. 43, 44, 67.

and 7, T. 46, R. 29 N., is described by Foster,[*] and later by Foster and Whitney,[**] who state:

"Passing back from the brow of the cliff for fifty feet, the mass was found to consist of micaceous and granular oxide of iron; to this succeeded a band of white, granular quartz, with particles of iron, disseminated, and, also, large rounded masses of the same material in the nature of a conglomerate, or perhaps, a breccia, fifteen feet in thickness, succeeded by a specular iron exposed in places to the width of one hundred feet, to where the soil and trees concealed all further traces. This iron for the most part, contains thin laminae of quartz arranged in parallel plates, bearing, so near as we could judge—for the day was dark and rainy and a compass was of no avail—north of west and inclining 82° northeast—corresponding with the strike and dip of the quartz rock. Other portions present a granular structure and are highly magnetic. Veins of quartz, with iron glance, cut through the mass, presenting external characters altogether different from those of the containing rock. This ridge crosses section one, township 46, range 30, and rises eleven hundred and nine feet above Lake Superior. Here, in this cliff, is sufficient iron, though not as rich as the Carp River region, to supply the world for centuries." Afterwards attention was called to this by Brooks,[†] who pointed out another conglomerate having the same position at the New England Mine. (Ibid. p. 133.)

(*c*) Brooks recognized plainly two quartzites, one of which underlay and the other (often conglomeratic) overlay the iron series (Ibid. pp. 83, 106–109). Some of the greatest difficulties with Brooks's work appear to be his failure to recognize the eruptive nature of the diorite and other associated rocks, and his view that the ore formation was all included between the two quartzites.

(*d*) The present writer twelve years ago also called attention to the quartzites and conglomerates composed of the underlying jaspilite and ore, as indications of old beaches, but as he considered these rocks eruptive the conglomerates could only prove sequence of time and not difference in geological age.[‡]

Rominger made out as the succession of the crystalline rocks included in the Cascade, Republic and Holyoke formations the following, commencing with the oldest: [§]

"I. Granitic group.
II. Diorite group.
III. Iron group.
IV. Quartzite group.
V. Arenaceous slate group.
VI. Mica schist group.
VII. Serpentine.
VIII. Eruptive dikes.
IX. Fissure veins."

Various exposures of conglomerates were described by him, all of which (Ibid. pp. 36, 42, 62-69, 95) appear to belong to the Holyoke formation, but the conglomerate at the base of the Republic formation appears to have been overlooked.

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[*] Senate Documents, 2d Sess. 30 Cong., 1848–49, III, Doc. 2. p. 161; Executive Documents, 1849, III, 775.
[**] Report on the Geology of the Lake Superior Land District, 1851, II., pp, 22.
[†] Geology of Michigan, I., pp. 128, 129.
[‡] Proc. Bost. Soc. Nat. Hist,, 1880, XX., 478, 479; Bull. Mus. Comp. Zool., 1880, VII., 30, 31, 59, 70, 74, 75.
[§] Geol. of Michigan, IV., p. 8.

(*f*) Irving formerly divided the rocks which are here treated as belonging to the Cascade, Republic and Holyoke formations into two series, about which he says:[*]

"The stratiform rocks themselves are, in fact, made up of two entirely distinct sets;[†] an older series of very intensely altered and crumpled true crystalline schists, in the main of a greenish color, which are invaded intricately by the granite at their contacts with it; and a newer, feebly altered, mainly fragmental series, whose contacts with granite and the schists of the older basement are such as to render the intervening structural break very evident. * * * * * * * *

"The *upper* series is mainly composed of detrital rocks usually little more altered than in the Lake Huron Huronian; the most abundant being quartzites. These are of various phases, ranging from the most vitreous quartzite to only slightly indurated sandstone; but all are genuine fragmental rocks. A clayey admixture is often present, and then at times pressure has developed a schistose structure and a secondary sericitic ingredient; but even in this case there is no difficulty whatever in detecting the essentially fragmental character of the rock. By increase of this clayey ingredient we have a gradation into the clayey shales and slates, which form the next constituent of the series in order of abundance. These present many phases, ranging from arenaceous to earthy in texture, being at times cross-cleaved and again not so, when they are little more than clay shales. They include also some very highly carbonaceous kinds. Next to the detrital rocks in importance, and often presenting gradation phases into them, is a series of what we may speak of as chemical sediments, though these have often undergone very great changes since their first deposition. Here belong the various calcareous and dolomitic rocks, the cherty or jaspery ferruginous schists and iron ores, and the actinolitic ferruginous schists. Most, if not all, of these ferruginous rocks have been derived from bedded iron carbonates by a process of silicification, as I have endeavored to show elsewhere, the unaltered or little altered carbonate at times remaining in considerable bodies. Besides these two classes of sediments, or alteration deriviates from sediments, there are included also considerable thicknesses of diabasic greenstones in the shape of eruptive sheets."

(*g*) Concerning the conglomerate that separated the two formations, Irving stated,[††]

"In one case, as for instance, that of the east line of Sec. 2, T. 47, R. 25 W., we have merely a fine detritus from the contiguous granite; but in most cases large blocks and pebbles of granite, gneiss and schist occur in the slate or quartzite at the contact. The occurrences on the S. E. quarter of Sec. 29, T. 48, R. 25 W., only about three miles west of Marquette, and those in Sec. 22 and adjoining sections of T. 47, R. 26 W., south and southwest from Goose Lake are very striking; but possibly those in sections 8 and 19 of T. 49, R. 28 W., in the vicinity of silver Lake, are yet more so. In this vicinity the older rocks, consisting of granite and schist involved with one another in such a way as to render irresistible the conclusion that the granite has intruded the schists, form a bold range sloping abruptly down to a lower area occupied by the softer detrital rocks. At the foot of the granite range the detritals, in contact with the granite and schists, are found crowded with fragments of both, of all sizes, up to pieces several feet across. The fragments are partly angular, lying in a breccia against the granite, and partly well-rounded."

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[*] Am. Jour. Sci., 1887, (3), XXXIV., 251, 253.

[†] "As first suggested by myself in 1883 (Fifth Annual Report U. S. G. S., p. 190) and more definitely announced in 1884."

[††] Ibid. pp. 254, 255.

(*h*) The same conclusion was arrived at in the Menominee and Gogebic districts. Of the former Irving says, [*]

"All the arguments that applied in the Marquette region in favor of the existence of a discordance between the two formations, apply here again. The basal conglomerates of this series are particularly finely developed, and may be seen on a grand scale at the contact of the basal quartzite with the granite at the falls of the Sturgeon River. * * * * * *

"Thus in the Marquette, Menominee and Penokee districts there are great discordances between a *lower* set of gneisses and other crystalline schists, intruded by granite, and an *upper* set of detrital rocks, carrying iron. In all three districts, moreover, the two sets of rocks seem so manifestly the same, being, indeed, very probably directly continuous through all, that we can hardly doubt that in all of these districts we are dealing with the same discordance."

(*i*) From this it is evident that most, if not all, of the unconformities observed by Irving were those which separated the Holyoke from the Republic formation, and that he placed at the base of the lower iron-bearing rocks the conglomerates composed of their debris. While Irving was correct in the observation of the conglomerates, he was wrong in his views of their position in the geological column, and thus actually overturned the series. This mistake of Irving's exercised a powerful influence upon his work and upon his views concerning the origin of the iron ores and jaspilite.

It is very unfortunate and confusing in the history of geological opinion concerning these basement conglomerates, that Van Hise has overlooked this mistake of Irving's and speaks[†] as if Irving had the same views as himself, i. e., that the conglomerates overlie the lower series of iron-bearing rocks, when Irving clearly and distinctly held that these conglomerates were at the base of all the iron-bearing rocks.[‡] Although in his latest publication Irving placed a greenstone schist area below the conglomerates, he yet retained all the iron-bearing rocks above them,[§] and did not separate the iron-bearing rocks into two divisions as do both Van Hise and myself.

(*j*) The recognition of the divisibility of crystalline rocks into three divisions was first published by the present writer in a paper dated Jan. 23, 1891, entitled "A Sketch of the Geology of the Marquette and Keweenawan Districts,"[‖] 2d ed., pp. 75–99.

In this article it was stated concerning the Marquette region that the before metioned fragmental deposits of ore and jaspilite were abundant in many portions of this district, in a large number of localities of which they form the only portion of the rocks worked for iron ores that the Michigan Geological Survey has thus far examined. At Negaunee in the Jackson mine, pit No. 7, which lies only a short distance from the railway station, these fragmental deposits make up the chief mass of the ore formation now exposed. Here the latter can be observed to pass upwards into a quarzite.

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[*] Ibid. p. 256.

[†] Amer. Jour. Sci., 1891, (3), XLI., 117, 121.

[‡] Am. Jour. Sci, 1887, (3), XXXIV., 253, 258.

[§] Bull. U. S. Geol. Sur., No. 62, pp. 19, 20, and 30.

In "Lake Superior and Along the South Shore," by Julian Ralph. New York, 1891.

The contact can be seen on the northeast side between the non-fragmental, or original, deposit and the secondary fragmental deposit made up of the debris of the former.

A few rods south of this pit the detrital jaspilite can be seen resting on the upturned edges of the non-fragmental jaspilite.

In many places about the Jackson mine, and to the north of the mine, the fragmental overlying jaspilite formation can be seen, often passing in its upward continuation into a well marked quartzite—a passage which is very common, especially when any great thickness of the fragmental deposit has been left. The schists about the Jackson mine also, in places, contain fragments of the ore and jaspilite. The fragmental jaspilite and ore are abundant about Ishpeming, especially at the Cleveland and Lake Superior mines. The old surface workings north of the Cleveland mine office show these deposits, with their overlying quartzites, excellently well, especially in the pit that contains the suspension, or swinging bridge, and in the one that has the inclined plane for footways. It will be seen that all these deposits are water and frost deposits made out of the debris of the iron formation, and that they gradually pass from deposits containing much ore and jaspilite, more or less angular, into deposits containing almost nothing except water-worn sand grains that form a quartzite.

At the Lake Superior mine the "Big W," figured by Brooks (Geol. of Mich., 1873, I, 245), to prove the sedimentary origin of all the ore formations, is nothing except one of these overlying deposits of fragmental ore. jaspilite and quartz, made up chiefly of the detritus of the underlying true ore formation, whose origin was the point in question.

At Republic and Humboldt the formations at present observed appear to belong wholly to the fragmental ones, in which the detrital ore has been concentrated, either mechanically or chemically, in sufficient abundance and purity for the purposes of the miner, the Republic having been until recently one of the leading iron mines of Michigan. About Republic there may be seen, overlying the fragmental ore formation, a second fragmental formation made up of the debris of the former, together with much quartz. This latter formation in places passes into a true quartzite.

At Sec. 15, T. 48, R. 26, where explorations have been carried on for workable bodies of iron ore, the fragmental deposits of iron ore and jaspilite still exist, and form, as at Republic, the ore deposits, so far as found.

In the Cascade range all the formations of jaspilite and ore studied in 1890 are of the fragmental kind. Here the jaspilite as well as the ore occurs in distinct rounded fragments forming layers which are frequently interlaminated with quartzite. Overlying this detrital formation is another detrital deposit unconformable with it, and composed of water-worn debris derived in part from the underlying fragmental deposit of jaspilite and ore.

We have now to consider what the facts mentioned in the preceding pages require for their explanation in the light of the principles also given, i. e., that an eruptive deposit can yield its detritus as soon as the deposit has been formed; but a sedimentary one, except some clays, must exist for a long while, and be consolidated and more or less changed, before its well-marked fragments can be deposited in an overlying formation of sedimentary origin. It should also be remembered, that the fragments of jaspilite and ore in the overlying detrital deposits before mentioned are banded, and possess the same character as the underlying non-fragmental deposit. Further, these fragments stand at every angle in the deposit, while the banding varies with the position of the fragments, showing that it belonged in the fragments before they were broken from their parent bed, and was not produced in them subsequently. From the above statements it follows that every one of these fragmental deposits marks a distinct geological age in the Marquette district, unless the underlying formation be of eruptive origin. If the latter was the case, then it might mean merely sequence of time, but not necessarily difference in geological age.

In the Cascade range, if the hornblende schist mentioned in Chapter III. is of true sedimentary origin, the overlying deposit is of a later geological age, but if the schist is a metamorphosed eruptive rock, then no geological division could at present be established there if it were not for the denuded veins. As stated before, the overlying granite and schist debris passes upward into a fragmental jaspilite formation that has been, and now is, mined about the Volunteer mine for iron ore. This fragmental formation is here supposed to be of the same geological age as the workable fragmental formation at Republic, Humboldt, etc.

Overlying this fragmental formation comes a second deposition of fragmental material, which shows that here exists a true geological break or age, forming a series that is younger than the first detrital deposit supposed to be derived from a non-fragmental jaspilite and ore. This last or overlying formation is best seen at the Cascade range, at Republic and at Holyoke. The above data render it then probable that in the Marquette district there are three distinct geological formations or ages, if not more.

1st. The hornblende schist and granite of Cascade or Palmer and the supposed non-fragmental jaspilite and ore of Ishpeming and Negaunee,—the Cascade formation.

2d. The fragmental jaspilite and ore, with their associated quartzites and schists, of Cascade, Republic. Humboldt, and elsewhere,—the Republic formation.

3d. The overlying conglomerates, quartzites and schists of Cascade, Republic, Ishpeming, Negaunee, Holyoke and elsewhere,—the Holyoke formation.

Various working hypotheses may be suggested to account for the observed facts; as for instance, if it could be proved that the supposed non-fragmental jaspilite and ore of Ishpeming and Negaunee are truly fragmental. their present relations being due to sedimentary and chemical action, and the squeezing together of the jaspilite and schist, then these rocks should be put into the second or Republic formation.

From what we know at present it is possible that further study may make out of these three formations at least four and possibly six different ones, or it may reduce them to two (l. c. pp. 85, 86).†

The work of the Survey during the past year has confirmed most of the views of the preceding year, which have mainly been stated above, and gives strong evidence that the two breaks mark geological time-divisions. It also indicates that at least two formations will be found in the Cascade formation, while it is probable that a second time-break will be established in the Holyoke formation.

(*k*) Prof. C. R. Van Hise, * in a paper read Dec. 30th, 1890, and published in February, 1891, before the printing of my paper, which gives him the priority, had independently arrived at the same conclusion concerning the two time-breaks.

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* Am. Jour. of Sci., 1891, (3) XLI., 117-137.

† Since this was written there have been added the Mesnard and Negaunee formations and the Michigan period. See my Report for 1891-1892.—M. E. W.

He does not appear, however, to bring forward any evidence of the break below the Republic formation, and the credit of showing the evidence and indicating its real significance in the Marquette district belongs to the Michigan Survey.

The names used by Van Hise are given opposite the corresponding names used by the Michigan Survey.

Cascade Formation = Fundamental Complex.
Republic Formation = Lower Marquette Series.
Holyoke Formation = Upper Marquette Series.

Van Hise, speaking of the Penokee-Gogebic region,[*] points to a cherty limestone over which is deposited a quartzite or a quartz slate, which in its turn is overlain by iron-bearing rocks of the Gogebic. At the base of this quartzite is, in places, a detrital or conglomeratic deposit, although Van Hise does not consider that it marks any geological break of any appreciable magnitude.

Does not the limestone, however, represent the Republic formation, and the overlying conglomerate with the quartzite the base of the Holyoke formation, to which formation the Gogebic iron ores are considered by the Michigan Survey to belong? In a later publication,[†] however, Van Hise also advocates this view.

The general conclusion of the Michigan Survey, that the ores of the Metropolitan and Menominee regions belong to the Republic formations and that the more western ores like those of Crystal Falls belong to the Holyoke formation would appear to agree with the views of Pumpelly and Van Hise.[‡]

(*l*) Professor N. H. Winchell also calls attention to and figures the overlying Holyoke conglomerate and quartzite at Palmer, which he rightly regards as derived from the underlying ore formation.[§] As nearly as can be ascertained, he considers all this overlying material as the equivalent of the Potsdam of New York. He also figures or notices some other locations (*Ibid., p. 46*).

Later, Winchell in his very valuable work on the iron ores of Minnesota (by N. H. and H. V. Winchell), has placed the lower iron formation, or Republic, in the Keewatin, and the upper iron formation, or Holyoke, in the Taconic. This was published later[‖] than the division given by the Michigan Survey and these divisions have the difficulty of bringing in various disputed questions of stratigraphical geology (*Ibid., p. 159, 160*). Winchell specifically considers the Penokee and Gogebic ores and the soft ores east of Negaunee to belong to the upper, or Taconic, and the Jackson mine to the Keewatin.

Winchell's division of the ores of Minnesota places them in four groups, which according to him belong to four distinct geological formations[††] and which may be summarized as follows:

1st. The magnetites of the Vermillion schists, answering to the Cascade formation of Michigan.

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[*] Tenth Annual Report of the United States Geological Survey, I. p. 446.

[†] Am. Jour. Sci., 1891, (3), p. 130.

[‡] Ibid., p. 133.

[§] The Geological and Natural History Survey of Minnesota, 1888, XVI., 44, 45.

[‖] See, however, an earlier publication, Report Geol., Minn., 1889, XVII., 68. In this work the Michigan iron ores are mainly placed in the Taconic. l. c., p. 48.

[††] Ibid., pp. 159-162.

2d. The Keewatin hematites and jaspilites, answering to the Republic formation.

3d. The Taconic formation containing non-titanic magnetites, jaspilitic hematites, soft hematites and titanic magnetites. This answers to the Holyoke formation.

4th. Limonites of Cretaceous age.

If Winchell's divisions are correct, then in Minnesota there exists a formation from which a debris similar to that in the Republic formation of Michigan could be derived, and it emphasizes the need of a more critical study of the Cascade formation in Michigan to discover the source of the overlying ores, to ascertain if the deposits are of economic importance.

§ 8. In the light of the preceding account of the subdivision of the rocks associated with the ores and jaspilite, one can return to the chemical (sedimentary) origin of the jaspilite and ore.

Before doing this, attention should be called to the fact that Irving, Van Hise and N. H. Winchell all agree that the jaspilite is not a mechanical deposit, or a deposit to which the term sedimentary is usually given. All, however, make exactly the same mistake that the present writer did in 1879. The supposed non-fragmental jaspilite is made to include a large amount of detrital jaspilite whose fragmental character and interbedding with indurated sandstones (quartzites) can now be clearly shown. The apparent non-fragmental character of the typical jaspilite was believed by me to be due to devitrification (chemical action) of an acid eruptive rock, and by the other observers mentioned to chemical substitution or chemical deposition in the ocean waters. To repeat, this brings to notice again one important line of investigation that ought to be taken up and carried much further. First, what is the source of the iron ore and jaspilite in the Republic formation, and second, are the ore and jaspilite of the lower formation at Ishpeming and Negaunee fragmental and do they belong to the Republic formation, or are they of non-fragmental character and do they belong to an older formation, from the debris of which the Republic formation is derived?

(*a*) Irving, as before stated, presented a theory that the ore and jaspilite were derived from an original carbonate.* His views are summarized by him as follows:

(1) "The original form of the beds of the iron-bearing horizons of the Lake Superior region was that of a series of thinly bedded carbonates interstratified with carbonaceous shaly layers, which were also often impregnated by the same carbonate. The carbonate was generally more or less highly ferriferous, though probably there were intermediate forms between it and dolomite. With these unaltered layers there seems to have been some little magnetite, in the shape of a fine dust mingled with the carbonaceous impurities, but most of the magnetite now found is taken to be secondary. Such a series of layers finds parallels in the carbonates of the coal measures, which present us, in some cases, with bands of an iron carbonate interstratified with carbonaceous seams, and in such bedded carbonates as those on the east side of the Hudson River, about six miles below Hudson, New York. With these latter ores also there is much carbonaceous matter in bands. The so-called black band ores of the coal measures are also at times very close in appearance to the black slaty ferruginous layers of the Animiké series.

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* Am. Jour. Sci., 1886, (3), XXXII., 270, 271.

(2) "By a process of silicification these carbonate-bearing layers were transformed into the various kinds of ferruginous rocks now met with in this region. The silicification varied in degree from those cases where a few thin seams of silica traverse the otherwise unchanged rock, or follow its lamination, to those in which there was a complete substitution, the iron being wholly leached out, in which case the lighter-colored cherty forms were produced.

"Moreover, these similarities are not macroscopic only, but extend also to the thin sections, a large number of which have been made for comparison from coal measure ores, and from the Hudson ores above mentioned.

(3) "The iron thus removed from the rock at the time of silicification passed into solution in the percolating waters, to be redeposited in various places as it became further oxidized, thus making ore bodies and various impregnations, and again forming the coloring matter of the jasper, the finely interlaminated hematite of which is taken to be mainly the result of a secondary infiltration following the banding of the original rock, though we imagine the hematite bands to have formed by direct oxidation from iron carbonate seams.

(4) "In other places, however, instead of leaching it out more or less completely, the silicifying waters seem to have decomposed the iron carbonate in place, producing a magnesia-silicate, or magnesia-iron-silicate, the excess of iron oxidizing imperfectly and separating out as magnetite, and the excess of silica crystallizing finally as a minutely interlocked quartz gorundmass. Thus have arisen most of the actinolitic magnetite schists. The various intermediate forms met with between the magnetitic and jaspery or cherty hematitic schists may be explained by the carrying out simultaneously of the processes of removal of the carbonate and of its decomposition in place.

(5) "The bodies of rich ore have probably had different origins in different cases. Some of the red hematites seem to have resulted from a direct oxydation in place of the original carbonate. This is demonstrable in the case of some of the thinner seams of hematite by the retention of the crystalline form of the carbonate, but most of the red ores and specular ores, between which there are many gradation varieties, seem rather to be the result of the concentration of the iron by leaching. It is quite noteworthy that, except in the case of certain magnetite mines, all the ore bodies are associated with great developments of jaspery or cherty silica, or both; i. e., they occur where the silicification has been most thorough, and where there has been the greatest amount of leaching of the iron carbonate. Some of the magnetite mines appear to be working on what are merely richer parts than usual of the magnetitic schists; but there are other cases of magnetite deposits, as also of deposits of specular ore, for which I do not now see any satisfactory explanation, though the difficulty comes chiefly, I suspect, from lack of sufficiently close acquaintance with them.

(6) "Some of the silicifying process went on before the folding of the formations; but some also afterwards, and to the latter period appear to me to belong the larger bodies of crystalline ore, the crumpling and shattering of the layers affording the best conditions for the action of the silicifying waters."

(*b*) Some of the objections to Irving's views may be briefly noted as follows:

1st. He starts out with a denial (*Ibid., p. 256*) of the phenomena that he ought to explain as they exist, and are now seen and studied by the Survey with which he was formerly connected.

2d. So far as now observed by the Michigan Survey the siderite is secondary, as are the alterations to which Van Hise also appeals to show the formation of the ores. The phenomena described by Van Hise appear to me to be mainly, if not entirely, due to surface action on the iron-bearing schists, and can be seen in any region. They are here believed to be subsequent to, and not prior to, the ore deposits, except so far as the ore deposits are even now forming. It is also here held that the usual process is the reverse of that given by him at the Sunday Lake outlet.*

3d. It ignores the fact that the Republic and Holyoke formations (the formations then principally studied by Irving) are composed in part of fragmental jaspilite, ore, and quartzite composed of rounded water-worn quartz grains, all intimately interbedded.

4th. No evidence indicating the correctness of Irving's views has thus far been obtained by the Michigan Survey in the Marquette, Menominee and Gogebic districts. The production of some ores by the alteration of the ferruginous dolomite is seen here, but only of a local and minor importance, and is the same as the alteration and decay of such rocks everywhere.

(*c*) N. H. Winchell published later than Irving a theory of chemical substitution which he expressed as follows:†

"*Was the ore the result of chemical, or metasomatic, change in sedimentary rock?* It is most in keeping with the facts, taken altogether, to attribute such an origin to the ore. The ore, as a mass, embraces sedimentary rocks of varying texture and composition, and throughout it can be seen the variations of texture and structure that only sedimentary action is known to produce in rocky strata.

"I have imagined that the hematite, as a superinduced feature of originally sedimentary rocks, had been substituted for some soluble or removable constituent, and perhaps by the removal of lime, since the present position of the strata was acquired, or contemporaneous with the acquirement of that position. It may be supposed that alternating thin bands of fine siliceous sand, fine shale and a soluble limestone could, when the proper chemical agencies were brought to bear, be converted into the jaspilite with all its banding, the fine sand becoming granular quartzite, the shale becoming the red and brown jasper, and the limestone the pure hematite; when the shale had some ingredient of carbon it would make the black jasper or the black siliceous slate. The extreme fineness of all the constituent grains of this rock (the argillitic, the sericitic and the jaspilitic) would suggest the possibility of the accumulation of a fine-grained lime-sediment which would be subject to all the chemical enemies that carbonates encounter. But the relative time at which such a supposed substitution of iron for limestone may have taken place is yet with me a matter of uncertainty."

Winchell later greatly modified his views, stating:‡

"The Keewatin hematites and jaspilites were derived from chemical precipitation in Keewatin time from the Keewatin ocean which, while essentially an ocean of hot alkalinic water, was disturbed continually by volcanic action and by the acid rains that volcanoes produce. The Keewatin rocks are almost entirely attributable to volcanic agencies as to the origin of their materials, but to sedimentary agencies as to their structure. The chemical origin of the jaspilyte as an oceanic precipitate is inseparably connected with and proves a like origin of the hematite. These hematites, being convertible by hydro-thermal agency into magnetites, and the Keewatin rocks by the same cause to schists and gneisses, are almost unknown in the Atlantic border region, where it is to be presumed that this metamorphism was greater than in the interior of the continent, and their placed is hence supplied by the 'Laurentian' gneisses."

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* Amer. Jour. Sci., 1889, (3), XXXVII., 39.

†Geological and Natural History Survey of Minnesota, 1887, XV., 245, 246.

‡The Iron Ores of Minn., Bull. Minn. Geol. Sur., 1891, VI., 161, 162.

These views are more fully expressed in the following:*

"Chemical precipitation in hot oceanic waters, united with simultaneous sedimentary distribution might produce the Keewatin ores in a manner consistent not only with the physical conditions that prevailed at the time of their formation, and with the structural peculiarities which they exhibit, but also in accordance with the known reactions of heated alkaline waters and with the chemical character which the ores are known to possess."

§9. In order to ascertain the composition of the jaspilite, some analyses were made by Mr. F. F. Sharpless with the following results:

	1.	2.	3.
SiO_2	80.34	80.84	80.59
Al_2O_3 (average)	1.73	1.73	1.73
Fe_2O_3	15.74	16.16	15.95
K_2O (average)	1.69	1.69	1.69
	99.50	100.42	99.96

The jaspilite was carefully separated from the mechanically mixed ore so as to give for the above analyses as nearly chemically pure a material as could be obtained. Some of the iron given above as Fe_2O_3 was seen in the form of Fe_3O_4, but it could not be separated.

§ 10. The work of the Michigan Survey has shown that considerable territory formerly considered to belong to the rocks here classed as Cascade, belong to later formations and hence can be considered as iron bearing. Two special areas can be pointed out which were located in 1885, when the Survey was under Mr. Wright's direction. The first added about forty square miles, mainly in the Yellow Dog River valley, extending from the former known area to the centre of T. 50, R. 28. The second area added about thirty square miles in the Silver Lake district, the rocks being traced southeast into T. 48, R. 26. An analysis of a hematite ore (No. 420) from the Silver Lake region gave Mr. Wright the following results:

SiO_2	19.72
Al_2O_3	12.56
Fe_2O_3	59.46
CaO	2.05
MgO	3.53
Mn_2O_3	0.72
P_2O_5	0.245
	98.285

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*Proceedings of the American Society for the Advancement of Science, 1889, XXVIII., 235-242.

Argillite and Schist.

§ 11. In direct association with the jaspilite and iron ores occurs much argillite and schist, a large part of which is of a sedimentary character and contains pebbles, while part of it is due to the alteration of eruptive rocks as previously mentioned.

These argillites and schists belong both in the Republic and in the Holyoke formations. Such of them as belong to the Republic formation are both older and younger in sequence of time than are the jaspilite and ore.*

The underlying argillite and schist appear to have been deposited in part with the underlying conglomerate and quartzite and to grade up into the fragmental jaspilite. Argillite and schist to a greater or less amount have been deposited interbedded with the jaspilite and ore in places, and they also succeed the latter rocks and overlie them. Care should therefore be taken to distinguish the argillite and schist that belong to the Republic formation from those that belong to the Holyoke.

The eruptive schists will be spoken of later in connection with diabase. diorite, and felsite.

The schists associated with the argillite are nearly always chloritic and one may be seen to grade into the other. Near the iron ore both are generally filled with crystals of magnetite and martite, while in many localities they contain garnets. tourmaline, chloritoid, etc., which minerals apparently occur in the Holyoke argillite and schists as well as in those of the Republic formation.

(*a*) The sedimentary argillites and schists of the Republic formation. so far as the observations of the Michigan Survey show, are older than the diorites of this region and are cut by them.† The altered diorites closely approach in their schistose characters and general appearance the sedimentary argillite and schist, yet with care and under favorable conditions their junction lines can be seen and figured, and hand specimens can be obtained showing this junction (*Ibid. pp. 40, 41*).

Granite and Felsite.

§ 12. In the Upper Peninsula there have occurred eruptions of granite. one or more of which are older than the detrital jaspilite of the Republic formation, if not older than any of the ore-bearing rocks, while another one or two occurred subsequently to the eruptions of some of the old basaltic rocks, or some of the diabases or diorites. These later granites have had a marked effect upon the geology and topography of the country, apparently cutting out the schists over large areas and changing much of the schist into gneiss. When the granite possesses a banded or fluidal structure, it is called gneiss; but that term, the writer thinks, ought to be restricted to the metamorphosed, foliated, sedimentary rocks composed of quartz, feldspar, and mica or hornblende, or both, and in that sense the term gneiss is used throughout this paper. while the term granite is employed for the eruptive rocks that have a granitic structure and composition, whether they are foliated or not.

Gneiss and granite are abundant to the south of Ishpeming and in the vicinity of Republic, Humboldt, Champion and Michigamme.

Granite can be found in North Marquette, at the mouth of Dead River.

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* It is always to be understood that in speaking of the jaspilite and ore, in this work, the hard ores are always intended unless the term *soft ore*, or *soft hematite*, is used.

† Notes on the Geology of the Iron and Copper Districts of Lake Superior, 1880, 36-49.

on the west side of Presque Isle, and upon the islands and shore to the north and northwest of that point.

(*a*). Sugar Loaf is one of the prominent granite hills North of Marquette. The granite is composed mainly of quartz, feldspar and hornblende, with some chlorite and mica. So far as observed, it is somewhat coarser grained than some of the ornamental granites; but it is suitable, if properly selected, for all heavy buildings, warehouses, dwelling-houses, piers, foundations, paving, monuments, etc., that is, for nearly all of the uses to which granite has been put. The size and shape of the blocks also indicates that it could be advantageously quarried in large masses. The writer's attention was particularly called to this location by Mr. J. M. Longyear. A good porphyritic granite is found in the vicinity of Republic. At Crystal Falls another granite occurs that would apparently make a good building stone, while Foster and Whitney in 1851 called attention to the granite of the Huron Islands and recommended its use. The present writer has for years, long before he became a resident of the State, urged the development of the granite industry in this region, on the ground of the rapidly increasing use of granite, the immense amount of it in the district, and the all important fact that direct water carriage exists to the large cities of Chicago, Detroit, Milwaukee, Cleveland and Buffalo, as well as to a hundred other Lake ports; while the only United States granite now known that can come into competition with it must be brought by rail from New England, Missouri, Minnesota, Wisconsin or some other interior locality. Most of the granite brought from the before mentioned places is of no better quality nor appearance than Lake Superior granite, while it is not improbable that more careful investigation would reveal other grades than those before mentioned.

It would appear that while part of the granite belongs to the Cascade formation, much of it was erupted during the time of the Republic formation, if not even as late as the time of the Holyoke formation.

(*b*). Most of the felsite apparently belongs to the Republic formation, although some of it is possibly of the Holyoke formation. The felsite is quite commonly erupted along the lamination planes of the associated schist, or country rock, but at other points crosses the foliation. It is usually greenish white, grayish or pinkish, shows a fluidal structure and holds crystals of quartz and feldspar, and usually some pyrite.* It is very common in the Gold region to find quartz veins by the side of these felsite dikes. The felsite is in some localities often altered into argillite and schist, probably giving rise to some of the dikes of this material that extend across the country.

(*c*). An analysis of granite from Gull Island (No. 11460), made by Mr. F. F. Sharpless, gave the following results:

SiO_2	69.88
Al_2O_3	14.86
Fe_2O_3	2.41
FeO	1.01
CaO	2.06
MgO	0.17
K_2O	8.00
H_2O	1.61
	100.00

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*Notes on the Geology of the Iron and Copper Districts of Lake Superior, 1880, pp. 38, 39.

Diabase, Diorite and Porodite.

§ 13. Many basic eruptive rocks originally of a basaltic or andesitic character, which in their altered condition are now called diabases, diorites, porphyrites, argillites and schists, are found to be intrusive or forming overflows in the Cascade, Republic and Holyoke formations. While it is not possible yet definitely to give the age of all these basic eruptives, the evidence thus far obtained indicates that the greater part of them which are associated with the iron ores are younger than the ore and jaspilite of the Republic formation, and part are at least younger than part of the Holyoke, and are discussed with that formation.

The forcing of these immense masses of liquid basaltic material through the strata was accompanied by a squeezing and upturning of the earlier formed rocks, so that we now find the iron ore and jaspilite with their associated schists and quartzites lying against the sides of the eruptive diorites or forming the intervening low grounds. These basaltic rocks, being later comers, have cut out the others, and frequently broken through the lower portions of ore and jaspilite, effectually barring further working of the ore in that direction, although Mr. S. A. Parnall, Chief Mining Engineer for the Cleveland and Iron Cliffs Mining Company, informs me that in these mines workable bodies of ore have been found extending under some of the diorite massess. It is not improbable that many of these diabase or diorite masses are the roots of old volcanoes.

(*a*) Many mistake the altered basalts, that form the schists, for sedimentary schists, but careful observation will determine where one ends and the other begins. The two look closely alike and are similar to each other in composition, but do not pass into each other any more than water and oil do, although an observer might not see the line of separation between the two.* The contacts of the two formations can be seen to the east of Ishpeming on a hill just north of the Cleveland mine, as well as elsewhere at points where the altered and schistose diabase and diorite come in contact with the sedimentary schists. The contact of the hornblende schist with the diabase and diorite can be well seen in many places about the northern part of Marquette where cuttings have been made, also where the break-water material was quarried, and upon Light House Point. Perhaps the most easily accessible places for the study of the old and altered basaltic rocks, with their associated schists, are in Marquette and vicinity, as well as along the railroad lines from Marquette to Ishpeming and beyond. The diabase and diorite form high rounded hills, often with precipitous sides, and they may be known by the greenish or greenish gray color of the rock. Good examples may be seen south of Ishpeming in the hill lying between the Lake Angeline and the Salisbury mines, also to the north of Negaunee, between that city and Teal Lake. Here occurs the roughly columnar structure common to basaltic rocks, the columns being perpendicular to their contact surface with adjoining rock masses.

(*b*) If the general discussion of the geology of this region is followed, it can be seen that prior to 1879 all geologists except Foster and Whitney considered these diorites as sedimentary and interstratified with the adjacent sedimentary rocks, and for the most part of prior origin to the iron ores. (*Ibid. pp. 27–40.*) Foster and Whitney considered the diorites as eruptive, and in 1879 the present writer found proof to show that they were not only eruptive, but that in general they were younger than the jaspilite and ore, uplifting and cutting the latter as dikes. (*Ibid. pp. 36–52, 69, 70, 75.*)

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* Notes on the Geology of the Iron and Copper Districts of Lake Superior. 1880, pp. 40, 41.

At the time of my examination it was generally claimed that the argillites and schists passed by insensible gradations into the diorites and schistose diorites adjacent. This view was shown not to be correct, but it was shown that the eruptive diorites were themselves so metamorphosed that they formed argillites and schists, almost identical with the sedimentary forms of that name; still they did not actually pass into the sedimentary schists and argillites. (*Ibid. 40, 41*). The separation of the two was found to be very difficult, and it was not expected that in general, on the surface or in diamond drill cores, such contacts would be commonly seen by observers, and such now appears to be the case in the work of some of the geologists, as has previously been pointed out in this paper.

Since 1879 Irving, Van Hise and Williams have agreed in the observations of Foster and Whitney, and myself, on the eruptive nature of the diorites, although Irving apparently considered them older than the iron-bearing rocks, and even fell (amongst other misunderstandings) into the singular error of considering that my work and views applied only to the later subordinate and well marked dikes, mostly of a diabasic character, about which there had been much less difference of opinion.[*] My views applied plainly to the rocks by Brooks denominated "Diorites, Dioritic Schists and Related Rocks (Greenstones)"[†] which comprise a very large portion of Irving's "Greenstone Schists," in the Marquette district.

(*c*) In this connection it may be well to correct a very striking error in Williams's work, in which he describes the transition of eruptive diabases into sericitic schists at the Lower Quinnesec Falls.[‡] This error is apparently due to a failure to observe the well marked conglomeratic structure of the rock on the Michigan side of the falls which shows that the main rock at these falls is not a massive eruptive diabase or diorite, but a porodite (an old eruptive ash or conglomerate). There were some felsite dikes and possibly some dikes of diabase and diorite in the porodite, but owing to lack of time, when the observations of Mr. Seaman and myself were made, it could not be fully determined whether they were dikes or only the more compact and finer grained portions of the porodite. Of the fragmental and conglomeratic nature of the rock no one can possibly doubt after studying it on the Michigan side, below the falls, and then tracing it back into the finer grained and more compact part near the bridge. So good an observer as Williams could hardly have been led astray, if he had examined the whole ground. A similar mistake seems to have occurred at the Upper Quinnesec Falls. (*Ibid. pp. 96–110.*)

(*d*) Porodites appear to be quite common in the Republic and Holyoke formations, but are more apt to be seen in the former.

Porodites occur associated with the diorite on Sec.s 17 and 20, T. 47, R. 28 N. The diorite cuts the iron series here as well as at Humboldt. The porodite is composed now of alternating bands of amphibole schist and light colored quartzose material holding bomb-like fragments. Here the porodite flanks the diorite hills to the north in such a manner that it appears to have been derived from them as a volcanic ash—the diorite hills representing the old volcanoes. Associated with these altered tufas is an amygdaloidal, or melaphyr, rock which appears to be a later eruptive. It can not yet be stated whether these porodites belong to the later Republic or to the Holyoke formation.

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[*] Bull U. S. Geol. Sur., 1890, No. 62, pp. 77, 81.
[†] Geol. of Mich., 1872, I., 99–104.
[‡] Bull. U. S. Geol. Sur., 1890, No. 62, pp. 84–95.

(*e*) The diorites can be seen and well studied in the vicinity of Humboldt and Republic as well as in various other localities, some of which have been mentioned before.

At Humboldt and Republic the dikes run generally parallel with the strata of the ore and jaspilite, so much so that Brooks considered them interbedded. By tracing the contacts one can see that the diorite in places breaks directly across the iron bearing rocks and then, after cutting them some distance, again spreads out and follows along the foliation, producing sometimes a laccolitic structure, as may be seen on Sec. 13, T. 47, R. 29, W., southeast of Humboldt.

The margins of the Humboldt dikes, and sometimes their entire masses, are altered to chlorite, and usually have garnets, amphibole and tourmaline either along the edges or scattered throughout the mass.*

The diorite is seen also to cut the Republic formation near the line between Sec.s 18 and 19, T. 47. R. 26, N.

Porphyrites.

§ 14. A system of dike rocks, of which only a few dikes have been noticed, occurs along the shore and on the adjacent islands northwest of Marquette. The structure is distinctly porphyritic. The groundmass is usually more or less felsitic, holding porphyritic crystals of feldspar and often of hornblende. Lath-shaped feldspar is seen in some of the specimens, which have a somewhat diabasic structure, while others have a more granitic structure. The color of these rocks varies considerably even in the same dike. They are usually reddish brown to gray or greenish gray. The relations of these dikes, as far as they have been made out, would place them in sequence of time next to the diorites. One of these dikes (No. 11,537) may be seen on the west side of Partridge Island, extending in a north and south direction, cut by three younger systems of dikes, *i. e.*, the youngest diabases, the melaphyrs or picrites, and the uralitic diabases. Another smaller porphyrite dike occurs on Middle Island. Its course is north and south. None of the later dikes, however, were observed in contact with this dike. On section 10, T. 48, R. 25, one of the porphyrite dikes is seen to cut the granite and runs N. 25° E.; it is in turn cut by the younger diabases. On Middle Island Point, Sec. 3. T. 48, R. 25, another of these dikes was observed that has a course almost due N. and S. This dike is cut by the three younger systems, as was observed on Partridge Island.

Another dike running N. 10° W. (No. 11,694), similar to the one just described, was observed on a small island N. W. of Partridge Isle. The rock is reddish brown to brownish gray, holding porphyritic hornblende and traversed by seams of epidote.

This rock is seen in direct contact with three diabase dikes. One has a course 20° E. of N., and cuts diagonally through the porphyrite. Both are cut at their intersection by two diabases that have a N. W. course. Other similar porphyritic dikes (No. 11375) have also been found. One cuts across South Picnic Isle, and is seen there to be itself cut by a melaphyr or picrite dike. A dike (No. 11573). similar to the last, cuts across Picnic Point a little N. of E. This dike is confined to the diorite and was mistaken by me in 1879 for a fragment of an inclosed schist,[*] as but a small portion of it was then seen. On Sec. 33, T. 49, R. 25 a dike having a N. and S. course cuts granite. This is a porphyrite of a greenish gray color.

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* Notes on the Geology of the Iron and Copper Districts of Lake Superior, 1880, pp. 47–49.

The porphyrites show many characteristics that would lead one to suppose that their metamorphism would produce rocks similar to the schist dikes that cut both series of the iron-bearing rocks. Neither the porphyrites nor the felsites have been shown to be younger than the Holyoke formation, and if they are not, then the diabases are the only recognizable rocks in this region to which the schists can well be referred. The view that the felsite or porphyrite may form the dikes of argillite or schist here considered is one based purely on their lithological characters, as otherwise no evidence has been found to sustain it.

Analyses were made by Mr. F. F. Sharpless of some of these porphyrites, to aid the Survey to obtain some idea of their chemical relations.

Porphyrite Analyses.

	No. 11,537.	No. 11,694.	No. 11,375.	No. 11,573.
SiO_2	59.14	56.26	62.38	63.52
Al_2O_3	22.61	19.14	14.66	18.01
Fe_2O_3	2.71	3.29	3.10	2.85
FeO	1.54	2.44	1.84	2.57
CaO		5.10	4.50	5.00
MgO	0.10	3.73	3.26	3.18
Na_2O		3.04	3.47	
K_2O	10 80	3.87	4.58	0.85
H_2O	0.96	2.00	1.54	1.60
	97.86	98.87	99.33	99.58

CHAPTER V.

THE HOLYOKE FORMATION.

§ 1. As is the case with the preceding formation, the Holyoke may be conveniently considered under its varied lithological divisions as follows, commencing with the lowest so far as is known:

1° Conglomerate, breccia and conglomerate schist.
2° Quartzite.
3° Dolomite
4° Argillite, graywacke and schist.
5° Granite and felsite (?).
6° Diabase, diorite and porodite.
7° Peridotite, serpentine and dolomite.
8° Melaphyr or picrite.
9° Diabase and melaphyr.

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[*] Notes on the Geology of the Iron and Copper Districts of Lake Superior, p. 39.

Conglomerate. Breccia and Conglomerate Schist.

§ 2. In the discussion of the Republic formation it has been pointed out that an unconformity exists between that formation and the overlying Holyoke, and the locality of a number of the conglomerates has been given. If the underlying rocks were all eruptive, this unconformity need only signify sequence of time and not a difference in geological age.

It has, however, been found that the jaspilite and ore of the Republic are in part at least detrital, and the fragments of this detrital jaspilite are seen in the overlying Holyoke conglomerate, the latter in absolute contact with and resting upon the former.

(*a*) This can be seen on Sec. 32, T. 47, R. 26, N., where a conglomerate occurs with an interbedded quartzite striking N. 60° E., and dipping northwesterly at an angle of 17°.

The conglomerate here is somewhat like that found at the base of the underlying Republic formation, but it contains a far greater number of waterworn granite pebbles than that does, as well as numerous angular and worn fragments of the underlying detrital jaspilite and hematite. In places where the upper conglomerate and quartzite overlie the other series, the two series are nearly conformable. But there are some localities in which the Republic formation seems to have formed high sea cliffs, which have been broken down in great masses. On Sec. 15, T. 48, R. 26 N., there is unconformity between the two. The underlying formation is a banded slate and jasper with some bands of hematite or limonite. This is unconformably overlain by a conglomerate that contains many fragments of the underlying rocks. Here the fragments, as a rule, were more angular than those observed elsewhere. A conglomerate on Sec.s 1 and 2, T. 48, R. 27 N., at the old Holyoke location, contains many large fragments of an iron series. The unconformity is also well marked at the old Goodrich mine, Sec. 18, T. 47, R. 27 N., and can be seen well at the Saginaw, Fitch and Winthrop mines, also at an old pit about one-half mile north from the Winthrop, and at the Superior, Cleveland, New York, Jackson, Humboldt, Michigamme, Republic, Kloman and Volunteer mines. At many places where the Holyoke formation has been traced, it overlaps the granite or gneiss area. In such cases it does not contain fragments that apparently belong to the Republic formation, or it contains them at most only sparingly, hence one might easily think he had here the base of the entire iron bearing formations.

The conglomeratic schists are often quite chloritic, and pass into chlorite schists and argillites without showing any trace of their conglomeratic structure.

At Crystal Falls a conglomerate can be seen in and near the bed of the river, marking an apparent uniformity, while the strata can be seen to have undergone a very great pressure, and exhibit some remarkable folds, some of which have a very sharp angle. Conglomerates occur on Sec.s 8, 14 and 23, T. 48, R. 28 W.; on Sec.s 1 and 2, T. 47, R. 25 W.; and Sec. 29, T. 48, R. 25 W. On the line between Sec. 30 and 31, T. 48, R. 28 W., the Holyoke conglomerate is found resting directly on the Cascade formation.

Quartzite.

§ 3. Associated and interbedded with the Holyoke conglomerate is a quartzite which often forms heavy and well marked beds like the Mt. Mesnard and the Teal Lake quartzites. Sometimes this quartzite, more or less conglomeratic, forms the base of the conglomerate and rests directly on the Republic formation, with the detrital jaspilite and ore of the Holyoke lying above.

(*a*) Such an occurrence at the Republic mine has proved very deceptive. It was figured by Brooks as a tongue of quartzite (Plate VI.). This was unquestionably due to his belief that the overlying ore formation was the same as the underlying. The present writer, without questioning the statement that the two formations were the same as mapped by Brooks, examined this supposed tongue at two places at which it had been cut across by some drifts. Here the tongue was found to contain along both sides, numerous rounded and irregular fragments of the jaspilite and ore, while the centre of the mass was comparatively free from them. At the points examined it varied from a few inches to two feet in width and was seen to break across the lamination of both the underlying and overlying rocks, and even sent small stringers into them. As all these rocks are thoroughly welded to one another and as all the above described phenomena are common in connection with eruptive rocks breaking through laminated ones, and as the supposed quartzite microscopically possessed the characters of a variety of granite known as greisen, it was considered to be eruptive.* It is to be remembered that it was only this tongue that was considered to be eruptive, and it was not taken to be quartzite, but a variety of granite. This gives no authority for N. H. Winchell's statement that the present writer regarded the quarzite at Republic as eruptive.†

Examinations since made by the writer and other members of the Michigan Survey show that immediately under the quartzite is an old erosion plane on the surface of the Republic formation, upon which at first considerable sand mingled with jaspilite and ore was laid down or in which they filled cracks; then followed a time in which the deposit was mainly quartz-sand; this in its turn passed into another mixture of ore, jaspilite and quartz-sand. This again was overlain by jaspilite and ore, sometimes in immense slabs, sometimes in the form of a fine mud with stringers of quartz-sand about some of the slabs or ramifying through the consolidated mud and iron sand. Since this deposition the entire mass has been subjected to intense chemical action, so much so that the overlying fragmental jaspilite and ore of the Holyoke formation look closely, if not exactly, like the underlying Republic formation, the two being separated only by the quartzite band. This quartzite is not, however, in the form of a tongue, as figured by Brooks, except when it fills fissures, but can be followed the entire length of the bluff, forming its surface in many places. The chemical alteration before mentioned has caused the quartzite to recrystallize, so that it is now composed of quartz, amphibole, greenish mica, epidote, magnetite and hematite. The quartz contains fluid cavities, mica, and numerous microlites, while the amphibole was seen to extend through two or more of the quartz grains as would be expected in an eruptive rock, but, according to our knowledge at that time, not in a sedimentary one.

When the above facts are considered, with the additional fact that the entire formation now stands almost vertical, the striking resemblance of this basement quartzite to a dike of greisen would be easily seen, if only cross sections as seen in 1879 were observed.

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* Notes on the Geology of the Iron and Copper Districts of Lake Superior, 1880, pp. 34, 54.

† Proc. Am. Assoc. Adv. Sci., 1889, XXXVIII., 237; Iron Ores of Minn., 1891, p. 393.

Similar chemical alterations are very commonly found along the line of contact between dissimilar formations of sedimentary origin, and they have given rise to much error and deception; to them a number of my mistakes have been due.

(*b*) Other localities have been observed at which, apparently by the action of frost or volcanic agencies, large clefts or fissures have been produced, in which the sediments of the Holyoke formation were deposited in such a manner as to produce the appearance of intrusive dikes. As a striking example of this, attention may be called to Sec. 20, T. 47, R. 26. At this place the overlying quartzite has been deposited in numerous joints and fissures of the lower iron series so as to give a reticulated vein or dike like structure to the mass on the eroded surface.

Similar phenomena were observed at the contact where the sand and silt had filled joints in the granite, on Sec. 15, T. 47, R. 46, south of Bessemer, and on Sec.s 8 and 19, T. 49, R. 28, near Silver Lake.

The Michigan Survey has considered that these conglomerates belong to the Holyoke formation, for they contain fragments of banded jasper that appear to have been derived from an older iron series.

The contact of the Eastern sandstone with the underlying rocks shows many extensions of this sandstone downwards into the older rocks, filling various fissures in them.[*] Similar filling of fissures in the underlying lava flows by the overlying sandstone have been commonly observed by the Michigan Survey and by others.[§] Similar phenomena on a large scale have been observed in California by Diller, who has given figures illustrating them and pointing to some other described localities.[†]

These forms are now so common that it seems necessary to have some distinctive term that can be used in descriptive language and prevent such forms from being confounded with true dikes and veins. I would therefore propose to designate the forms produced by the filling of fissures or cracks by sedimentary (mechanical) material, by the term clasolite (*clasis* and *lithos*). I would use the same term as a generic one, whether the fissures were filled by deposition from above or by earthquake or water action from below.

It is an open question whether some of the argillites and schists now found cutting the iron ore beds have not been formed as clasolites rather than as true dikes. A similar formation might be produced by soft clayey rocks, if, when the associated rocks were folded, the clayey material were squeezed into fissures or between beds.

(*c*) From what has been seen of the relations between the Republic formation and the Mt. Mesnard quartzites (if that in the vicinity of Palmer may be classed under the latter), it would appear that the quartzite is the later and belongs to the Holyoke formation. The exposed unconformity on Sec. 20, T. 47, R. 26, may have a bearing on this point. Further evidence has been given by a drill hole that has been bored at the foot of the large bluff on Sec. 29, T. 47, R. 26, north of the Wheat mine. The drill cut, first, about six hundred feet of quartzite; second, a conglomerate; third, a band of ottrelite schist; and further, penetrated several feet of good ore associated with the jaspilite. As we find exactly these conditions on Sec. 32, T. 47, R. 26, where the contact is exposed, there seems but little room for doubt as to the relative ages of the heavily exposed beds of quartzite and jaspilite in the Marquette district.

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[*] A Sketch of the Geology of the Marquette and Keweenawan Districts, 1890, p. 76.

[§] Ibid., p. 77, Foster and Whitney, Copper Lands, p. 87. Marvine, Geol. Sur. Mich., 1873, I., part 2, pp. 109, 113, 119.

[†] Bull. Geol. Soc. Am., 1890, I., 411–442.

On the N. W. ¼ of Sec. 36, T. 48, R. 29, a quartzite can be seen resting on the Republic formation, while quartzites of unknown age occur in Sec. 16 and Sec. 21, T. 42, R. 35, Sec. 13, T. 42, R. 36, Sec. 8, T. 44, R. 35, and Secs. 13 and 14, T. 44, R. 36. Some of these quartzites form quite high hills.

Dolomite.

§ 4. The dolomites have been discussed to some extent in connection with the Republic formation, but some remarks will be given here concerning those that are considered to belong to the Holyoke.

In the Mt. Mesnard district a dolomite associated with quartzite can be traced from the shores of Iron Bay inland as far as Goose Lake, a distance of about eight miles. In lithological characters it does not differ from that along the Michigamme River. It can not be definitely stated to which of the iron formations it should be referred, yet the work of the Michigan Survey during the past summer would indicate that it belongs to the Holyoke rather than to the Republic formation. If this is true, then lithologically it is quite probable that the Felch Mountain dolomites should also be referred to the Holyoke instead of to the Republic formation. The objection to this is, that in the Felch Mountain district the magnetite rocks associated with the dolomite are so similar to the iron strata of the Republic formation in the Marquette region, that one feels bound to consider them as belonging to the Republic until proof to the contrary is obtained, which, of course, would place the underlying dolomites in the Republic.

While a dolomite, or cherty carbonate member, has been recognized by Van Hise as belonging to the Republic formation, one is also mentioned by him as existing in the Holyoke, and although these rocks are of a different type from those above called dolomites, yet it is possible that there may be such siliceous dolomites in each series, but the data on this point are imperfect at the present time. The dolomites associated with the serpentines will be spoken of in connection with the latter.

Argillite, Graywocke, and Schist.

§ 5. If the Holyoke formation is traced westerly from Lake Michigamme, it is found that the upper horizon is composed of a peculiar grayish argillitic sandstone which contains some feldspar. The term graywacke has been used in the field to denote this sandstone, so as not to confound it in the notes with the Eastern sandstone. The graywacke of the finer kind may be said to grade into an argillite, and where it is coarser to pass into a mica schist. These graywackes have been found between Sunday and Gogebic lakes, where they seem to occupy the same horizon that they do further east. It is in the Holyoke formation that the black roofing slates occur, of which the Arvon slates are well-known for their superior quality, although the rock is so jointed that the waste appears to be too much at present for economic working.

On Sec. 2, T. 46, R. 37, the "Ayer Estates" are opening in these slates what promises to be a valuable quarry. The roofing slates seem, on the whole, to underly the graywackes, although they occur more or less interbedded with them.

As comparatively little has been done to develop the slate industry in this region, the area covered by this series is little known to prospectors. When it is considered that from Huron Bay southwest and south to the Wisconsin line, and that from Lake Michigamme west and southwest for fifty miles the greater portion of the surface rock belongs to this series, it seems quite probable that other localities exist in which good slate for roofing purposes may be found.

(*a*) Below is given the analysis of the slate No. 11994 from Arvon, from the quarries of the Michigan Slate Company, obtained through the kindness of the superintendent, Mr. C. M. Turner. The analysis was made by Mr. F. F. Sharpless.

SiO_2	57.030
Al_2O_3	19.486
Fe_2O_3	1.000
FeO	6.130
CaO	1.310
MgO	3.460
Na_2O	0.330
K_2O	5.450
P_2O_5	0.134
S.	0.100
C.	0.890
H_2O	4.750
	100.070

(*b*) Mica schist occurs around Lake Michigamme, and for some distance southwest.

Staurolitic mica schist was also found crossing the Michigamme River in a broad belt, in Townships 41 and 42. The latter location was mapped by Wright in 1879, and specimens were collected by the Michigan Survey in 1886. There are other areas of mica schist, but they do not belong to the iron series, and have never been traced out by the Survey except roughly.

The ore bodies of the Holyoke formation are found generally associated with the conglomerates, quartzites, siliceous schists, argillites and graywackes. They are often of large extent, and, outside of the Gogebic district, usually non-Bessemer.

The characters of the rocks in the Gogebic district, and the finding of pebbles in them apparently belonging to the Republic formation, cause the Michigan Survey to consider the ore formation there as of Holyoke age. The ores of Crystal Falls are considered to belong to the same age. In the Marquette district some of the mines believed to be located in the Holyoke formation are the Wetmore, Beaufort and Taylor.

Granite and Felsite.

§ 6. It is questionable if any felsite or granite of Holyoke age exists in this region. So far as seen, the evidence rests mainly on some apparently altered dikes of felsite which are now argillites or argillaceous schists.

Some of these occur in the vicinity of the Holyoke location, at the Goodrich, Saginaw, and some other mines, in the quartzite at the outlet of Teal Lake, etc. It is of course an open question if these rocks are altered felsites or if they may not be altered porphyrites or diorites. The writer concludes from what study he has been able to give the question, that the chlorite, amphibole, and a few mica schist dikes are more commonly produced by the alteration of basic eruptive rocks, while most argillite, argillaceous schist, and mica schist dikes are generally altered acidic rocks, particularly felsites and granites.

It is not known how far up the Holyoke formation these argillite and schist dikes extend, as they have mainly been seen low in the series, or near the basement. By far the larger number of dikes of this character are seen in the Republic formation, but this may be due entirely to the greater amount of mining done in that formation.

Diabase, Diorite, and Porodite.

§ 7. Beside the diorites that are found in the Republic formation, there are younger rocks of quite common occurrence that are closely allied to the preceding diorites on the one hand, and to still younger diabases on the other.

While these younger rocks can generally be called diabases, they often pass through alteration into diorites, showing in their augites various stages of transition. In fact the alteration of augites to amphibole was so marked in the rocks of the various formations studied by the writer in 1879, that he remarked concerning the various basic rocks (not andesites nor peridotites): "They would pass, according to the ordinary definitions, macroscopically and microscopically, for diorite, quartz diorite, diabase, chlorite schist, hornblende schist, etc., etc., yet we regard them all simply as more or less altered forms, according to age and conditions, of rocks that were originally the same in origin, structure, composition, and name—basalt." *

The special group of altered basalts taken up at this point generally occur in dikes that have a nearly north and south, or sometimes northeast and southwest, course. The rock is usually of a dark grayish green color, and weathers to a lighter grayish color.

These dikes are cut by two later groups of dikes which will be treated of subsequently.

The diabase and diorite dikes here under consideration are known to be younger than part of the Holyoke formation, because they are found in direct contact with the iron-bearing rocks of this formation, cutting across the bedding of the latter and folding and contorting the strata. As further evidence, it may be noticed that no pebbles of these rocks have ever been observed by the Michigan Survey to be contained in the conglomerates at the base of either the Republic or Holyoke formations. These rocks seem to be closely allied to the porodites that occur so abundantly in the vicinities of Ishpeming and Humboldt.

If the various argillite and schist dikes that cut the Republic and Holyoke formations can be shown to be altered diabases, it is probable that most of them belong to this group of diorites.

A peculiar group of amygdaloidal rocks or melaphyrs occur on the

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* Notes on the Geology of the Iron and Copper Districts, 1880, pp. 46, 49, 70.

Michigamme river east of Crystal Falls, and extend northwesterly in apparently isolated knobs. They are best developed on Sec.s 3, 4, 9, 10, T. 44, R. 33. These melaphyrs are apparently interbedded with porodites, and probably mark the site of the old volcanic cones.

In the chlorite and amphibole schist area north of Ispheming and Negaunee there is a system of east and west dikes that are cut by the before mentioned diabases. The east and west ones do not differ materially from the north and south dikes in composition, but their diabasic structure is obliterated, and they are ordinarily known as diorites. One such dike can be seen on Lighthouse Point in Marquette. Several other systems can doubtless be determined by further careful study, while many localities show porodites apparently belonging to some of the systems.

(*a*) Analyses of two of the diorites that cut the Holyoke formation are given below. They indicate that these rocks are either basalts whose silica has been relatively increased or else that they are altered andesites.

	No. 7.931. Sec. 2, T. 48, R. 27 W.	No. 10,040. Sec. 16, T. 42, R. 32 W.
SiO_2	54.11	55.14
Al_2O_3	12.09	15.03
Fe_2O_3	4.00	2.40
FeO	11.51	6.33
CaO	6.72	4.90
MgO	3.47	7.43
MnO	0.73	0.465
Na_2O	2.73	2.83
K_2O	1.49	3.10
TiO_2	0.85	0.40
P_2O_5	0.12	0.172
Cl	0.02	0.029
H_2O	1.39	2.06
	99.23	100.286

Peridotite, Serpentine and Dolomite.

§ 8. These rocks are exposed at Presque Isle and at the northwest of Ishpeming, beginning in the eastern part of Sec. 27, T. 48, R. 27, and extending in a southwesterly direction to Sec. 2, T. 47, R. 28. They are also to be seen in T. 44, R. 32, and in Sec.s 22, 28, T. 42, R. 31.

(*a*) The locality of Presque Isle is one of the most interesting ones in which to study the peridotite, as it occurs there well exposed, owing to its being washed by the waves of the lake. It is seen as a dark to black lherzolite, passing into a serpentine of the same color, and also into one of a green color, especially on the northeast side. The peridotite is worn into caves, and its surfaces traversed by a network of fissures filled with dolomite, chrysotile and silica, with occasionally some copper ores. Since accumulations of chromite or chromic iron ore, nickel ore, platinum, etc., are frequent accompaniments of the chemical alteration of peridotite, during the process of the formation of serpentine, explorers about the Ishpeming range ought to keep a careful watch for those substances.

A strongly marked fault or fissure along which the rock has moved, so that the different sides occupy a different position relative to each other than they formerly did, is to be seen in the serpentine at Presque Isle, a short distance north of the caves. Mr. Wright suggested as a solution of the difficult problems which the rocks present at Presque Isle, that there were two eruptions of peridotite. This view had much evidence to support it, but further study by the writer goes to show that the so-called two eruptions are phenomena caused by various fractures, fissures and joints, together with the unequal action of the percolating waters, as well as by a weathering. On the west side of Presque Isle one can find the granite with the serpentine adjacent. Excavations made by Mr. Seaman and myself prove to us that the contact of the two is an eruptive one, and that the peridotite is the later. The present writer showed in 1880 that this serpentine was originally a peridotite, or olivine rock, of the variety known as lherzolite—that is, composed of olivine, enstatite and diallage.[*] This peridotite, since the eruption, has been altered to a greater or less extent, forming a rock known as serpentine, while in many places the formation of dolomite and talc schist has also occurred as a result of the metamorphosis of the peridotites.

(*b*) The geological history of this rock is very interesting. Dr. Houghton thought that it was eruptive, and younger than the sandstone which was uplifted by it, believing it to be a greenstone impregnated with serpentine. He states that near the line of junction the sedimentary rock has been greatly shattered, and its fissures filled with injections of calcareous matter. Dr. John Locke thought the "light green trap" was interfused with the sandstone at this point.

Messrs. Foster and Whitney considered that this rock was an immense consolidated lava flow, although it wanted the vesicular structure, while the part filled with the white veins was regarded as a volcanic sand or ash deposited on the lava stream. Younger than this Azoic lava was the sandstone deposited upon it (Potsdam). A chemical analysis of it was given, but no name assigned to the rock. Later this was regarded as closely related to serpentine by Professor Whitney who gave three analyses of it[*]

Subsequently, Dr. Hunt, accepting Professor Whitney's analyses, regarded this rock as a somewhat impure sedimentary serpentine belonging to the Huronian series.

Dr. Rominger later regarded this rock as a half-decomposed basalt or highly ferruginous serpentine; the part filled with the veins was taken to be an older sedimentary rock, a dolomite, upheaved and broken by the trap, and overlain by the conglomerate and sandstone. This sandstone is supposed to have been deposited in the inequalities of the underlying rock, following its contours. He thought it most probable that the sandstone was deposited at its present inclination, although it may have been slightly upheaved since. The conglomerate beds at the base of the sandstone are said to contain numerous fragments of the underlying rock. I regarded this peridotite in 1879 as an eruptive rock, younger than the sandstone overlying it, and agreed in this particular with Dr. Houghton. The portion filled with veins, that was by him taken as a sedimentary rock belonging to the sandstone, or a mixture of sandstone and trap, by Messrs. Foster and Whitney as a volcanic sandstone or ash, and by Dr. Rominger as a dolomite, older than both the sandstone and trap—the writer regarded as simply the upper portion of the intrusive mass modified by its contact, while heated, with the overlying sandstone, and later by the percolating waters.

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[*] Notes on the Geology of the Iron and Copper Districts, 1880, pp. 60-66. Lithological Studies, 1884, pp. 136-138.

[*] Am. Jour. Sci., 1859, (2), XXVIII, 18.

(*c*) On the southern side the sandstone dips quite irregularly from twenty to thirty degrees southerly. The strata follow the curve of the underlying peridotite, forming in places anticlinals. The distinction between the sandstone and its underlying rock was everywhere seen to be well marked. The surface of the peridotite is in rounded knobs, the whole mass itself in general outline forming an immense knob. The sandstone and conglomerate were examined, and found to conform in their general stratification to the contour of the whole mass, having the same wavy outline; also, for from two to three feet above the peridotite, they are indurated, changed, and show characters that I then regarded as evidence of the action of heat and of hot waters. These sandstones and conglomerates are filled with vein and chalcedonic quartz, and hardened and reddened like the sandstone immediately underlying the melaphyr overflows in the copper district. Certain portions have been changed, so that they resemble a volcanic ash, although they are simply ferruginous sandstones. Above the limit of baked sandstone and conglomerate comes the unaltered ordinary red sandstone. Microscopic sections of the indurated conglomeratic sandstone show that much of the quartz is a secondary water deposit subsequent to the deposition of the fragments composing the rock. Irving and Wright from their observations were both inclined to consider that the Presque Isle serpentine was older than the overlying sandstone. Much more extended examinations since made by myself and others show at a few points small fragments of serpentine in the overlying sandstone. While to the naked eye much doubt existed whether these fragments were serpentine or not, the microscope enabled the question to be satisfactorily settled. The finding of these fragments in the overlying sandstone and conglomerate quite conclusively settles the question of the relation of the overlying sandstone to this mass. The evidence seems now clear that the sandstone was laid down at quite a high angle on the serpentine, apparently pushed along by strong currents so that it assumed an almost blanket form over the rough and irregular surface of the latter.

The strongly marked induration of the basement conglomerate is now found to be common in connection with most of the basement conglomerate seen in the Northern Peninsula, but does not occur at the classical locality at Carp River, described by Foster and Whitney. It is possible that the sandstone there is of younger age.

(*d*) At the locality north of Ishpeming the peridotite is more highly altered and is associated with much secondary dolomite that often forms quite large masses. The dolomite here is apparantly produced as at Presque Isle by the alteration of the serpentine. Frequently the dolomite and serpentine are irregularly blended together, forming the variety known as verde antique. No marble, in the proper acceptation of that term, occurs in the Marquette district, so far as is known, as that term belongs only to crystalline or ornamental limestones and not to serpentine.

The Ishpeming serpentine is in a belt varying from half a mile to a mile in width and is found to cut off and trend obliquely across the eruptive granites, felsites, diorites, diabases, etc., and not to be cut by any but the latest of the dikes that freely traverse the other rocks.

Further proof of the eruptive nature of the serpentine can be seen near the centre of the northeast quarter of Sec. 27, T. 48, R. 27. Here occurs a dike of serpentine about one hundred feet wide, with a strike somewhat east of north. This dike can be traced about two hundred paces, until covered by drift, and is seen to cut across diorite, diabase, and felsite.

On Sec. 31 of the some township the serpentine is seen in direct eruptive contact with diorite and chlorite schist, cutting them for some distance.

The above evidence would seem to render the proof complete that the serpentine is the youngest of the large intrusive masses seen thus far in the Marquette district.

It is also probably younger than any of the dikes except the youngest diabase and melaphyr.

Melaphyr or Picrite.

§ 9. A very peculiar and more or less schistose rock occurs especially well marked on the shore of the main land and on islands north of Marquette.

The rock is much decomposed and is of a dirty brownish or grayish color. It is cut by the dikes of diabase to be mentioned later, but cuts all the preceding rocks except the peridotite.

This rock is so highly altered that its determination is difficult, and thus far it has not been made out with any certainty. On account of its relations Mr. Seaman has suggested that it may be small dikes of the peridotite.

A microscopic study of these rocks by the writer has shown him that their structure was in part porphyritic, and that the crystal pseudomorphs are more likely to be after augite than olivine, although the proof is not decisive. In many respects the structure is like that of the andesites, but in a few of the more highly altered forms it resembles that of some of the altered peridotites. Again, in the least altered specimens, the structure is like that of some of the porphyritic melaphyrs.

(*a*) Chemically, however, the rock appears to be most closely allied to some of the altered peridotites, especially to picrite, as one can see by comparing the analyses of it, made for the survey by Mr. F. F. Sharpless, with analyses of the various peridotites.*

Analysis of Melaphyr or Picrite.

	I.	II.
SiO_2	36.66	37.17
Al_2O_3	10.22	4.54
Fe_2O_3	5.38	11.50
FeO	0.88	8.11
CaO	17.12	9.76
MgO	9.17	14.75
MnO	0.96	2.54
K_2O	0.20	0.59
TiO_2	1.44	----
CO_2	12.31	5.41
S	0.03	0.45
H_2O	5.75	5.46
	100.13	100.28

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* See table IV., Lithological Studies, 1884, pp. 18-31.
I. No. 11,445, from Middle Island, Sec. 35, T. 49, R. 25. W. Analyst F. F. Sharpless.
II. No. 11,447. Ibid.

These melaphyr dikes generally run northwest and southeast, and they have been seen more commonly in the vicinity of the peridotite than elsewhere. This may, however, be easily accounted for by two facts—first, that it is a region that has been much traversed by the Survey, and second, that no other region of the peninsula presents any more favorable conditions for studying geological phenomena than does this special part of Lake Superior's shores.

These melaphyr dikes are particularly well developed on the north and west side of Partridge Island, about five miles north of Marquette.

Diabase and Melaphyr.

§ 10. The youngest series of dikes observed in the Holyoke formation is a diabase which often contains olivine and some secondary quartz. These dikes are seen to cut the Cascade and Republic formations as well as the Holyoke. They are here regarded as later eruptions of the same basaltic material that has been traced down from its more altered stages to those that are less so, and variously called amphibole and chlorite schists, diorites, diabases, melaphyrs, etc.

The same general character of eruption apparently commenced in the Cascade formation, continued into the age of the Copper-bearing rocks, and in other regions this material can be found cutting rocks of every age, and now outpours from modern volcanoes.

The dikes under consideration here usually have a course nearly east and west, or a little north of east, although some are seen to run north and south, and northeast and southwest, but they are exceptions to the general rule.

The rock is usually of a dark gray color in the more coarsely crystalline central portions, while the margins are often of a dark bluish or grayish black color, and very fine grained or even glassy, forming melaphyr and zirkelite.

These rocks are well exposed in the vicinity of Marquette, and along the shore northwest from that place. They can also be traced west from Marquette, and be found to cut through the diorites that are intrusive in the Republic formation, as can be observed in the hill southeast of the Lake Angeline mine. They are also seen to cut through both the lower and upper iron series. One of these dikes with an east and west course was traced for some distance through the south part of T. 47, R. 37. The dike cuts through the slate obliquely, pitching south. In the same town are bedded flows.

In the vicinity of L'Anse and Huron Bay several of these dikes have been observed to cut the black slates and graywackes. There is a large dike of this kind exposed near the south line of Sec. 4, T. 49, R. 33, in a R. R. cut a short distance north of the Taylor mine.

Another large dike was seen to cut the argillites in T. 47, R. 34.

As further examples of these dikes, we would point out the one extending from Light House Point, Marquette, in a westerly direction near the north side of Sec s 24 and 23, and approximately following the line between Sec.s 15, 22, 16, and 21, 17 and 20, T. 48, R. 25; also the large dike cutting through the Mt. Mesnard quartzite on Sec.s 2 and 3, T. 47, R. 25. A similar dike cuts through the Republic formation near the Volunteer mine on the Cascade Range.

(*a*) That these dikes may have represented a long period of eruptive activity, and that successive eruptions often followed even the same line of fracture, is shown by the fine grained indurated contacts that exist in what at first appeared to be one continuous dike. They may often be seen to run in what looks like a split dike, holding portions of the country rock between their walls for some distance and then reuniting. Hand specimens of them have been taken, from which thin sections were made that show these contacts.

(*b*) None of these dikes have been observed to penetrate the Eastern sandstone along the shore of Lake Superior. On Little Presque Isle on Sec. 17, T. 49, R. 25, the sandstone is seen to rest undisturbed on a diabase which in the hand specimen very much resembles the diabases under consideration here, although under a lens it appears to be somewhat uralitized.

Of more importance, however, is the relation of these dikes to the peridotites north of Ishpeming. On Sec. 27, T. 48, R. 27, a diabase dike with an east and west course is seen to cut directly across the peridotite. Also on Presque Isle two or three narrow dikes of melaphyr with an east and west course are seen to cut the peridotite. At least one of the dikes that cut the serpentine on Presque Isle is overlain by horizontal sandstone in an undisturbed position. The evidence then would certainly indicate that the Eastern sandstone at this point and in these particular beds, is younger than the diabases; it does not prove, however, that all the Eastern sandstone is geologically younger than these dikes. Moreover, these diabase dikes with the east and west course are the only rocks observed to cut the serpentine or peridotite. This will be seen to have considerable bearing on the relative age of the peridotites, making them at least next prior in sequence of time to these diabases.

(*c*) It has been thought by Mr. Seaman, on the following grounds, that these diabases are the same as the copper-bearing rocks. On the Gogebic Range diabases having a course somewhat north of east cut through the iron series, and have played no small part in the concentration of the ore bodies. These dikes when associated with the ore are often much decomposed, but the diabasic structure is usually quite distinct. In the Keweenawan sandstone that overlies the iron series dikes may be seen to cut obliquely across the bedding. Whether these dikes are the same as those seen in the iron series is yet an open question, but Mr. Seaman thinks they are the same dikes both on account of their similar strike and dip, and lithological resemblance. At the point in which the dikes cut the sandstone they are usually much fresher in appearance than in the places in which they cut the iron series. A good illustration of the diabase cutting the Keweenaw sandstone can be seen on Sec. 9, T. 47, R. 46, on the south slope of the first hill northwest of the village of Bessemer. A similar rock, cutting obliquely across the lower Keweenaw flows, was observed about a half a mile further west. This rock shows the lath-shaped feldspars well developed in the central portions of the dike, while the margin is very fine grained. The course of the dike appears to be a little east of north.

Another dike that appears to be a typical diabase was traced through the northern portion of Sec. 14, T. 46, R. 41, just south of the nearly horizontal flows. This dike has sandstone for its walls. The sandstone is much indurated at its contact with the dike, and in fact might be called a quartzite. On Sec. 11, T. 46, R. 41, another dike or neck cuts through the sandstone, and on reaching the surface spreads out and forms one of the flows.

From the preceding observations it seemed to Mr. Seaman very probable that the diabases represent the necks filling fissures through which the Keweenawan rocks reached the surface and that the Keweenaw flows are the effusive equivalent of these later diabases.

Mr. Seaman states that while the above may not apply to the main Trap Range, it does seem to apply to the South Trap Range, and that it would seem to follow that, whatever may be the age of these flows, they are older than the Eastern sandstone. As evidence in support of this view, he mentions the occurrence of sandstone in the bed of the Ontonagon river near the centre of Sec. 13, T. 46, R. 41, and its apparent relation to the sandstone composing the bluff that forms the left bank of the river further west in the same section. The sandstone that forms the left bank of the river is conglomeratic at the base, and rests very unconformably on the steeply inclined green schists, and passing upwards is followed by about 40 feet of coarse, pebbly, but even-grained sandstone having a somewhat ferruginous, muddy cement. Above this comes a finer grained, much indurated variety with a somewhat lighter color. This outcrop can be traced east and northeast about 700 paces; it forms a cliff along the river for nearly 400 paces, when it bends northeast and forms a terrace, which recedes some distance from the river, owing to a broad, graceful curve of the latter. The terrace gradually diminishes in elevation, owing to the northward dip of the strata, for a distance of 300 paces to the northeast, where the river again approaches it. The elevation is not more than 10 ft. above the latter. The low terrace is here about 40 ft. from the river, and is composed of the indurated sandstone, almost a quartzite in its present condition. In the bottom and bank of the stream not more than twenty steps east, is a soft, friable, micaceous sandstone with a slight easterly dip. About 200 steps south, in the right bank of the river, the soft sandstone is seen again, still dipping to the east. Here it contains pebbles of melaphyr and large angular fragments of indurated sandstone, very much like that which forms the terrace. Another feature worth mentioning is that the friable sandstone contains numerous spherical spots of deoxidation, very common in the Eastern sandstone, while that which forms the terrace is devoid of these spots.

The finding of melaphyr pebbles in the friable sandstone, is, according to Mr. Seaman, no argument in favor of its being of a different age from the more indurated variety. He states, however, that as it contains fragments of the indurated sandstone, and as it is different in lithological characters from the latter, there can be to him but one interpretation, and that is that they are two sandstones of different and distinct geological age. The relations of one or both of these sandstones to the Eastern sandstone may be an open question, but he says that the later, or friable one has all the characteristics of the Eastern sandstone, so far as his observations have gone; while the indurated one, especially the pebbly portion, has to his knowledge no equivalent in the Eastern sandstones of Lake Superior. Another source of derivation of the indurated sandstone pebbles may be the iron series, but he does not think that any one could assume the two sandstones to be the same. He believes that the South Trap Range represents an overlap of the Keweenaw series, and probably holds a position near the top of the same, and also that as the flows and interbedded sandstone are undisturbed east of Gogebic lake, the steep inclination of the series west of the lake is due to cross faulting somewhere in the vicinity of the lake.

(*d*) Two specimens of diabase were analyzed by Mr. Sharpless. They were obtained from the Lake shaft of the Cleveland mine. No. 13,459 is a specimen showing the altered diabase as it occurs in the mine, where it has been freely acted upon by percolating waters. This action has brought about an apparent higher percentage of silica, alumina and water and diminished the amount of iron, lime, magnesium, titanium and alkalies, which have evidently been carried away to be stored up elsewhere. No. 13,456 is fresh compared with No. 13,459, but yet it is a rock that has been much changed from what it was in its original condition as a basalt, and we cannot now say what part of the elements now found in it, was in it originally—we do not know how much has been carried into it nor how much removed. No. 13,459 shows by its structure and appearance that it has been leached.

Analysis of diabase from Lake Shaft, Cleveland mine, Ishpeming:

	No. 13,456.	No. 13,459.
SiO_2	47.99	58.22
Al_2O_3	16.57	28.66
Fe_2O_3	6.01	2.56
FeO	5.13	0.22
CaO	9.36	0.17
MgO	6.01	----
MnO_2	trace	----
Na_2O	2.00	----
K_2O	1.39	----
TiO_2	2.71	----
H_2O	2.64	10.50
	99.90	100.33

CHAPTER VI.

CHEMICAL DEPOSITS OF THE AZOIC SYSTEM.

1. Chemical Deposits of Iron and Manganese, or the "Soft Iron Ores."
2. Veins, (Gold, Silver, etc.).

Chemical Deposits of Iron and Manganese, or the "Soft Iron Ores."

§ 1. Through the preceding pages illustrations have been given that show the chemical action of the percolating waters found in all rocks, for there is no known rock, unless exception be made of rocks in the form of glass, that will not absorb water to a greater or less extent. All these waters are chemically active, whether hot or cold, pure or not; but it is undisputed that heat, pressure and substances in solution in the water greatly increase its chemical activity. It has been pointed out that all rocks are modified or changed through the action of the chemically active waters, leading either to the decomposition of the rocks or to a change in their mineralogical composition, and oftentimes to a change in structure. It has further been pointed out that the alterations brought about by the chemical waters, with or without heat and pressure, have caused rocks formerly of the same character and composition to take upon themselves very diverse forms. It has also been noticed that rocks of entirely different origin and structure, like sedimentary and eruptive rocks, have been so changed by this action that the resulting forms are indistinguishable from one another except by their geological mode of occurrence.

All these changes in rocks have not proceeded without the removal of certain mineral matters from one locality and their deposition in another. A strong tendency is observed towards a localization of the removed mineral products, or towards special aggregation of mineral substances, some of which are economically of no importance, while others form useful ore deposits. This subject will be more fully discussed later under veinstones. The special accumulations of this material in the Azoic system that are of economic interest to us are the veins, and the "soft ore deposits" known principally amongst the miners as "soft hematites."

(*a*) Such igneous activity as that before mentioned could not take place in this region without the percolating waters becoming heated and their chemical and solvent action being greatly increased, for when the volcanic energies are dying, one of the last traces of the eruptive activity is shown in the hot springs.

The rocks amongst which so much eruptive matter has been forced are necessarily fractured, bent and twisted—the fractures serving as channels for the escape of the waters in the form of springs, or as underground streams. It is found in the Marquette region that the jaspilite, and the associated detrital rocks that contain iron ore have been greatly decomposed and affected by the percolating waters, apparently hot; and that as a result the silica has been leached out and the oxide of iron deposited in its place, or else the original iron ore has been left behind or locally concentrated. Through the action of these percolating waters many of the siliceous schists, chlorite schists, argillites, quartzites and jaspilites, which were formerly worthless as ores, have been rendered valuable by having their siliceous materials largely replaced by oxides of iron, etc., giving rise to the ores locally known as soft hematites, which occur principally in beds and carbonas. Oftentimes the ores are locally aggregated in irregular pockets and chambers from which the original rock had been removed.

The ores produced by the above described water-action are not only ores of iron like hematite, limonite and göthite, but also ores of manganese like pyrolusite, manganite, psilomelane, rhodochrosite and wad. Barite, as well as other minerals, is found associated with the manganese ores in the vicinity of Negaunee.

(*b*) The soft hematites naturally occur in places where the rocks have been more or less arched, or bent and broken. They are very commonly found in the low or depressed lands, and on their sides, which often form bog or lake basins between the diorite and diabase hills, or they may occur anywhere in their vicinity, at points where the fracturing would naturally be greatest and the water would best act, especially if the region was traversed by dikes. The Salisbury mine was first worked at a point at which a large diabase dike breaks across the country and cuts obliquely through the large diorite hill that lies between the Salisbury and the Lake Angeline mines. The writer pointed out twelve years ago, that on the

Lake Angeline side, at the point where this dike again cuts the jaspilite and schists, would be the most probable chance for finding another soft hematite mine, as at this point water action is going on even at the present day.

The soft ores are also found at a considerable distance from the diorite hills when any action has caused the rocks to form suitable channels for water, so that they have become more or less decomposed. These ores are found in both the Republic and Holyoke formations at any points where the conditions proved favorable for the transmission of water, especially at their junctions, and at any place where there has been sufficient ore for concentration.

Deposits of soft ore in the Marquette district in the Republic formation appear to be closely associated with the jaspilite which was originally the real home of the ore, and when the ore bodies extend into the schist they are usually found in connection with an adjacent jaspilite, and have been formed by local impregnation or replacement.

The soft ore bodies are so irregular in their distribution, particularly in the Marquette district, that no safe general rule can be given for finding them, except that they are associated usually with certain horizons of rock, and a careful study of the geological conditions in each place ought to give a fair idea of the probable occurrence of soft ore deposits in any district.

Veins (Gold, Silver, etc.).

§ 2. One of the latest phases of the formation of deposits of value has been the filling in of fissures by the water-deposited quartz and other vein materials, or, in case no crack nor fissure existed, by the removal of country rocks along certain lines and their replacement by vein matter.

Veins formed thus may contain only quartz or other valueless minerals or they may hold valuable metals and ores. It is in veins that the gold and silver north of Ishpeming are worked, the vein at the Ropes gold mine being in serpentine and diorite, while the others are in diorite, granite, felsite and schist. Quartz veins can easily be seen in the diorite hills about Ishpeming, and in many places elsewhere. While many deposits of ores or metals occur in veins, the most important ore deposits of Michigan do not so occur, except most of the gold and silver deposits and a few of copper.

(*a*) As an assistance in naming the various ore deposits of Michigan there is given below a scheme of classification preliminary to one that will be elaborated later. This classification is believed to be in many respects unlike any heretofore published, yet the effort has been made to use the common terms employed in such classifications, even if their customary definitions are somewhat modified. In this arrangement the writer is greatly indebted to the classic works of Van Cotta and Whitney, and to the later writings of Emmons, Grimm, Groddeck, Koehler, Newberry, Pumpelly, Raymond, Serlo and others.

The effort here made is to keep as near as practicable to the apparent methods employed by Nature in the production of metalliferous deposits of use to man, but to a greater or less extent the divisions are arbitrary and unnatural, both on account of the mixed nature of most ore deposits, and the imperfections of language, which has not words adequate to express the varied occurrences of such deposits. Hard and fast lines do not exist in any of Nature's formations, but we are obliged to draw such lines with more or less distinctness for purposes of description and as common standards of reference.

This is done with continuous time, by its arbitrary hours, days and years; with the earth by its equator, poles, parallels, and meridians; in common life by our artificial weights, measures, money; in short, such arbitrary lines are drawn in everything that man has to deal with or the human mind has to conceive.

Our terms and our classifications, taken entire, are the strings or the wire upon which we thread our beads of fact or fancy, so that we may have them united together for use, instead of their being scattered about. As the string is far less valuable than the beads, which cannot be used without it and can be changed at will, so, too, the theory or classification is far less valuable than the facts that it unites together, and it can be discarded for another at will, but without some such string to unite these facts together they are of no use to any one, It may in truth be said, that every man, in every walk of life, orders his work and governs his life by some theory or theories, however crude and imperfect they may be.

(*b*) A PRELIMINARY CLASSIFICATION OF METALLIFEROUS, OR ORE DEPOSITS.

- Eruptive Deposits
  - Non-Fragmental Deposits.
    - Flow Deposits.
    - Dike Deposits.
    - Mass Deposits.
  - Fragmental Deposits
    - Tufa Deposits.
    - Porodite Deposits.
- Mechanical Deposits.
  - Unconsolidated Deposits
    - Placer Deposits.
    - Bed Deposits.
    - Tufa Deposits.
  - Consolidated Deposits
    - Shale Deposits.
    - Sandstone Deposits.
    - Conglomerate Deposits.
    - Breccia Deposits.
    - Tufa Deposits.
    - Porodite Deposits.
    - Argillite Deposits.
    - Quartzite Deposits.
    - Schist Deposits.
    - Gneiss Deposits.

- Chemical Deposits.
  - Sublimations, or Vapor Deposits.
  - Water Deposits.
    - Spring Deposits.
    - Stream Deposits.
    - Bog Deposits.
    - Lake Deposits.
    - Sea Deposits.
  - Impregnations, or Replacement Deposits.
    - Eruptive Rock Impregnations.
      - Non-fragmental Deposits.
        - Flow Deposits.
        - Dike Deposits.
        - Mass Deposits.
      - Fragmental.
        - Tufa Deposits.
        - Porodite Deposits.
    - Sedimentary Rock Impregnations.
      - Bed Deposits.
      - Carbona Deposits.
  - Segregations, or Cavity Deposits.
    - Pocket Deposits.
    - Chamber Deposits.
    - Contact Deposits.
    - Veins.
      - Gash Veins.
      - Segregated Veins.
      - Reticulated Veins, or Stockwork.
      - Contact Veins.
      - Fissure, or Fault Veins.

(*c*) *List of the Principal Veinstones.*

Fluorides and Oxides.	Anhydrous Silicates.	Hydrous Silicates.	Phosphates.	Sulphates.	Carbonates.
Fluorite. Cryolite. Quartz.	Wollastonite. Pyroxene. Amphibole. Willemite. Garnet. Epidote. Mica. Scapolite. Nephelite. Feldspar. Tourmaline.	Laumontite. Prehnite. Analcite. Datolite. Talc. Serpentine. Kaolinite. Mica. Chlorite.	Apatite.	Barite. Celestite. Gypsum.	Calcite. Dolomite. Magnesite. Siderite. Rhodochrosite. Aragonite.

(*d*) Some little explanation and illustration of a few points in the above classification are perhaps needed. One is, that it is not my intention to limit this classification to those deposits that are of value to man this year, since what is valuable is a relative term, and varies from year to year, but I intend to include in it all metalliferous deposits known, that have been, now are, or may be, valuable to man. I expect, therefore, that it will be changed from time to time, as new information is obtained.

The *eruptive deposits* appear, so far as is now known, to be confined to iron either in the form of native iron, as at Greenland, or of magnetite, as the gabbro ores of Minnesota or that which occurs in cumberlandite, even if it may be proved that none of the Michigan ores are eruptive.

Outside of the *placer deposits* it would seem that the *mechanical deposits*, *e. g.*, clay, sandstone, conglomerate, argillite (slate), gneiss, etc., are for the present but little worked for the metal they contain, but rather for other uses, particularly for building and allied purposes.

The division of *mechanical deposits* into *consolidated* and *unconsolidated* is one that is not in all respects correct, since some of the placer deposits are much more compact and indurated than are some of our sandstones or shales. The term unconsolidated is here intended to include those forms of deposit connected with volcanic, air, water and ice action, that make up the superficial portion of the earth, and have not been formed into rock in the ordinary sense, but are generally known as drift, sand, loam, gravel, shingle, clay, tufa, etc., etc.

Sublimation, or vapor deposits are apparently not common, even if any are now worked.

The *water deposits* in Michigan appear to be mainly confined to bog, lake or stream deposits of manganese and iron ore, which have not up to the present proved of any great value.

The *impregnations or replacements*, are represented to a very large extent in the Michigan iron ores, in the copper deposits, and to some extent in the Gold Range, as set forth in connection with each subject.

Segregations occur in the Gold Range, and in part of the Copper District, but only very sparingly is the vein form seen in connection with the iron ore deposits, which, however, quite commonly occur in pocket and chamber deposits.

In most deposits impregnation or replacement, and segregation or cavity filling are intimately associated, so much so that a deposit often appears to belong as much to one as to the other. This is particularly so in the case of some of the Michigan copper deposits.

The term "contact deposits" is perhaps entirely unnecessary, as most forms classed under that name, or classed as contact veins, belong to chambers, pockets or segregated veins, fissure veins or impregnations. As impregnations they readily fall under some of the subdivisions given under that name.

§ 3. A *vein* is defined by Professor J. D. Whitney, as "an aggregation of mineral matter of indefinite length and breadth and comparatively small thickness, differing in character from, and posterior in formation, to the rocks which inclose it."*

This defination appears to be more true to nature than those given by most authors, who, while they give a similar definition, require a preexisting cavity to fill. This requirement does not appear to be necessary, since many veins exist that apparently have been filled by the removal of the rock simultaneously with the deposition of the veinstones. Such seems to be the case with the gash veins carrying gold that traverse dikes and flows of old eruptive rocks.

Such a definition is not fully consonant with the use of the term segregation as synonymous with cavity fillings, as cases like the above would be an exception to the rule unless a small cavity or fissure formed the nucleus of the vein. It is also apparent that most veins that do fill a cavity owe but a small proportion of their width to the original fissure, but rather to chemical dissolution of the wall rocks and the substitution of vein matter in their place.

To this and to the fracturing produced by the crystallization of vein material in the country rocks is due the common merolitic structure of so many veins, particularly those of Keweenaw Point.

Again, the motion of the country rock fractures the adjacent walls, and produces instead of the merolitic, a true brecciated structure, although the two structures are often associated together in the same vein.

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* Metallic Wealth of the United States, 1854, p. 44.

In one point in the above definition of a vein by Whitney a change is suggested. His definition, in common with those of most authors, for example, Phillips, Raymond and Van Cotta, is just as applicable to a dike as it is to a vein, and this Whitney intended it to be, for in many works in geology the term vein is made to cover both veins and dikes. The term "vein" can be made to include only mineral veins by defining it as *a chemical deposit of mineral matter* of indefinite length and depth (breadth) and comparatively small thickness, differing in character from, and posterior in formation to, the rocks which enclose it.

A dike on the other hand would be defined as *an eruptive deposit of mineral matter, etc.*

Again, each of the various sedimentary deposits of sandstone and other detrial materials that fill fissures, to which the writer gives the name of clasolite, can be defined as *a sedimentary deposit of mineral matter, etc.*

In order that the definition of a vein should not be misunderstood, it is, perhaps, better to substitute depth for breadth in Whitney's definition, since breadth as used here is apt to be mistaken for width or thickness. Depth, however, would not always be correct, since some veins are horizontal or nearly so, when both length and depth (breadth) would mean their horizontal extent, and thickness their vertical dimension. A further source of misconception is that later authors generally use the term breadth as synonymous with the term width or thickness.

(*a*) The term *gash veins* is given, in accordance with the usual custom, to a class of veins that are limited mainly or entirely to a single rock formation, i. e., when the mineral character of the rock changes, the vein ends. These gash veins are seen in diorite dikes, in limestone beds and in various other rocks. They usually extend across the rock nearly at right angles to its sides, although sometimes they may and do extend lengthwise of the rock formation or even in other directions. They are apparently formed by substitution of the vein material for the original rock by contemporaneous removal and deposition, or by the filling in of shrinkage cracks, or joints.

(*b*) *Segregated veins* may be considered as veins of limited length and depth (breadth) that extend into two or more different rock formations. They may be formed along joint planes, or by substitution, and usually have ill defined walls, although through some portion of the course the walls may be well defined. As gash veins grade into segregated veins and segregated veins into fault or fissure veins, it is very difficult, if not impossible, to draw the line between the different classes, and determine to which class some veins belong.

(*c*) *Reticulated veins* are usually a series of individual gash or segregated veins that, owing to their abundance and numerous intersections of one another, form a net work. The associated and interstitial rock is often impregnated with ore, and the entire mass is mined, the whole forming a stockwork.

(*d*) A *fissure, or fault vein* is one formed by the chemical deposition of vein material in a far reaching fault or fissure in the earth's crust, and is due to the latter's movements. The fissure is independent of the rocks through which it passes, but the veinstone filling may or may not be. As a rule the contents of the vein and its width are influenced more or less by the rocks through which the fissure passes. This is apparently due to the nature of some rocks that resist the fracturing of the walls, or else are not easily affected by the solvent action of the percolating waters of the vein, or else vary in metalliferous contents. The last cause is not so commonly operative as are the others, since the elements that fill the veins are often carried long distances before they are deposited. The deposition of the ore or metal appears to be dependent upon its being carried to a place suitable for that deposition, or where the proper precipitant can act.

§ 4. It may not be amiss briefly to point to some of the laws and conditions that govern the chemical deposition of ores, as such deposits appear to follow after and result from the various alterations and changes that have been going on in rocks.

Every kind of chemical deposit, even sublimation deposits, can be considered as resulting from the solution of mineral matter through the agency of the chemically active percolating or surrounding waters, which remove substances from one locality to another, or replace one material by another. While it is not always true, it is a general rule that ore deposits are most commonly found in regions of eruptive rocks either ancient or modern, as in connection with such rocks the percolating waters are apt to be warmest and most charged with chemically active solvents.

(*a*) The history of ore deposits seems to be the result of a *universal law* which affects all rocks of the globe and may be considered as the one which governs the entire universe, physical, mental and moral.

For the physical universe this can be best formulated, perhaps, as the *degradation and dissipation of energy, the passage from an unstable condition towards a more stable one, the tendency of all things to harmonize with their environment, that is with their surroundings, or with the conditions to which they are exposed.*

This appears to be the law under which the universe has moved from its beginning, and under which it will continue its course uniformly towards the end; no turning back can occur, and no energy once lost can be restored, except by the same Almighty Power which gave it birth. *

It is here proposed to point out the relations of this law to ore deposits, and to call attention to the uncertainty of conclusions drawn from the analyses of the wall rock and its contained minerals. In order to do this, it is necessary to present a brief but comprehensive view of the entire field.

(*b*) Without entering at all upon the question of the source of those rocks which have come from below the earth's surface and are known as eruptives, and which form a large portion of the so-called metamorphic series, it is sufficient for the present purpose to state again that, when they reach the exterior of the earth, their condition is one not adapted to the circumstances in which they are hereafter to exist. For a time, at least, prior to their eruption they have been under far different conditions from the atmospheric ones on the earth's surface; of necessity, there will be a constant tendency on their part to conform to these changed conditions. This is manifested most conspicuously in their loss of heat, and in their passage from a liquid to a solid condition. When solid, these rocks may be said to be in an unstable condition, in respect to their temperature, and also to the chemical combinations formed on solidification. Their chemical arrangements, as manifested in their constituent glass and minerals, are such as to necessitate a transference to a condition in which they will be less acted upon by the agencies to which they are exposed on the earth's surface, and this leads to a degradation, dissipation and loss of energy on their part. In other words, the rocks tend to pass from an unstable towards a more stable state. The rapidity of these changes depends not only upon the chemical constitution of the rocks, but also upon the special circumstances in which they are placed. In the basic rocks, or those containing much iron, magnesium, calcium, aluminum, etc., the alterations are comparatively rapid, but in the acidic rocks much slower. If rocks of eruptive origin are studied under the microscope, these alterations can be readily traced from their earliest to their latest stages, and are usually found to be in a ratio to the ages of the rocks or to the particular influences to which they have been respectively subjected.

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* Science, 1883. I., 541; Lithological Studies, 1884, p. 1.

(*c*) It is these alterations that have led to the multiplicity of rock names, and to the confusion of nomenclature; lithologists and geologists, as a rule, formerly supposing that as a rock then was, so it always had been and always would be. For example, the lava flows of Keweenaw Point, which were once identical with the modern basaltic lavas of Mt. Etna and of Kilauea, are now designated, on account of their alteration and age, as melaphyrs, diabases, diorites, etc.; andesite in its changed guise is designated as propylite, diabase porphyrite, porphyrite, diorite, etc.; rhyolite as felsite, quartz porphyry, petrosilex, orthofelsite, etc.; peridotites, or olivine rocks, as serpentine, talc schist, etc.

The propylite of the Comstock Lode is a striking example. The present writer was the first to call attention to the fact that the fortieth parallel propylites were altered forms of pre-tertiary and tertiary andesites.* The position then taken has been fully confirmed by Dr. G. F. Becker,† and by his colleague, Arnold Hague. Dr. Becker further states that every decomposed rock in the district has been taken for propylite.

(*e*) The above mentioned changes, or alterations, in rocks of the same composition appear to be largely dependent upon the action of infiltrating waters, and their rapidity seems in a ratio to the temperature of the water or to the solvents contained therein. These alterations appear to consist, in general, of molecular transferences or chemical reactions in the rock mass as a whole, and are not confined to special minerals; hence has resulted the failure of theories of mineral pseudomorphism to explain *rock* metamorphism, or alteration—the pseudomorphic changes in the rock mass being but the resulting accident of the greater and more general metamorphosis. In the process of alteration the original glass of the rock is broken up, forming various minerals according to its composition, while the original crystallized minerals are changed to a greater or less degree, the resulting minerals being quartz, various ores, anyhdrous and hydrous silicates, carbonates, etc. In the course of these changes there is everywhere seen a tendency to localize these secondary products, especially the ores, which results in the removal of material of one kind and the deposition of another in its place, or in the filling of fissures and cavities in the rocks. It is not uncommon to find in rocks minute veins that under the microscope show variation in their filling as they pass through different minerals. What has now been described as taking place in one rock takes place in all, and frequently with various interchanges and reactions between the different associated rocks. If we pass gradually from alterations seen in the rock and from the minute fissures observed under the microscope, to deposits visible to the unaided eye, to joint or fissure planes that traverse large masses of rock, or to cavities or to any condition of rock structure that will admit the chemical deposition of mineral matter, then, whether we have ore deposits or not seems to depend upon the activity of the alteration and upon the amount and kind of matter brought together. It is well known that valuable ore deposits are more apt to occur in regions of eruptive and altered rocks than elsewhere.

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* Bull. Mus. Comp. Zoöl., 1879, Vol. V., pp. 281, 285, 286.
† Geology of the Comstock Lode and Washoe Districts, 1882, pp. 12-150.

From what has been said above of the general alteration of rock masses and the partial localization of their contained mineral matter by percolating waters, it would appear that this cause gives rise to all chemical deposits, even to sublimations when the water is vaporized.

Instead of the re-deposition of the mineral matter, taken up by the percolating waters, in the rock or in contiguous cavities, it may be borne far away, appearing in spring, river, lake, and ocean waters, and in deposits laid down by them, precipitation taking place wherever the proper conditions exist.

(*f*) Of all theories that have been proposed to account for ore deposits, there are few that are not correct for some form of ore deposits in certain localities, while the practical use of these theories is to aid us in understanding the nature of the deposits, as a guide to their exploitation. The difficulty in the use of these theories lies in their abuse, through their indiscriminate application to all deposits. Our rule ought to be to study every deposit thoroughly, and after the study, not before, apply that theory which best answers to the observed conditions, since all theories ought to be generalizations or expositions of observed facts, with a prophecy for the future.

(*g*) It is not doubted here that all ore deposits, not of a mechanical or eruptive origin, can be attributed to the general alteration and change in rocks, that result from the general dissipation and degradation of the potential energy of the constituents of the earth's crust, in the universal passage of matter from an active towards a passive and inert condition.

This general alteration manifests itself in a universal chemical or molecular transference—a transference of material, leading to the segregation or localization of the ores in the places in which they are now found; it manifests itself in the deposition of mineral matter in the veins and cavities of the rocks themselves, in deposits from springs, in bogs, lakes, etc. From this it would follow that all ore deposits, not eruptive, are, as regards the earth, superficial phenomena and dependent on its external agencies, although they may be deep enough, so far as man in concerned.

Again, few of these ore deposits would be expected, except in regions in which percolating waters and their attendant metamorphism have been efficient agents;* while the various forms of ore deposits would be associated with, and grade into, one another.

§ 5. It is now proper to examine upon what basis the results rest that several geologists have claimed to attain, through the analysis of the altered rocks that are associated with the various ore deposits.

If we start, as all geologists do, with the belief in an originally hot fluid globe, all rocks must have been derived, primarily, from fluid material, which contained all the elements of the metals or ores. The detrital rocks would naturally partake of the metalliferous character of the rocks from which their material came, and each would develop similar changes; while in the chemically and organically formed rocks, in accordance with their special conditions of formation, there can readily be suggested agencies for the precipitation of useful ores throughout their mass, during the time of their formation, the precipitated ores being gathered up subsequently in all those rocks by the percolating waters.

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* Whitney, Contributions to American Geology, 1880, Vol. I. The Auriferous Gravels of the Sierra Nevada of California, pp. 310, 331, 350, 356.

(*a*) In order to draw any conclusion concerning the reliability of deductions regarding the source of the ore—conclusions based on the analysis of the minerals in the country rocks adjacent to an ore deposit, it is necessary to look into the question of the origin of these minerals. It has been found, that if the point of consolidation of rocks be taken as a reference point, the minerals of these rocks naturally fall into three classes:

(1) Those of prior origin—foreign.
(2) Those produced by solidification (crystallization)—indigenous.
(3) Those produced later by alterations in the rock mass, or by infiltration—alteration, or secondary.†

The first can conveniently be separated into two divisions:

(1) The minerals that are characteristic of the rock, whatever may be its locality or age.

(2) Those that are accidental, as for instance, fragments caught up during the passage through or over another rock.

Any rock may have in it all three classes or only one or two as the case may be. A few minerals may be cited in illustration: olivine in the peridotites is an indigenous mineral, but in the basalts is foreign, although generally characteristic of them. Serpentine, when not an infiltration or veinstone product, is always a secondary, or alteration product. Hornblende in the recent andesites is foreign, but in the older andesites and in almost all the older rocks of every kind it is either a secondary product or is a more or less altered mineral. The micas, feldspars and quartz occur as foreign, indigenous, and secondary products. As a rule, in the modern rhyolites quartz is foreign, but in the older rocks of this type, felsites and quartz porphyrites, it is both foreign and secondary. All hydrous oxides and silicates and all carbonates appear to be alteration products.

As a rule, the different modes of occurrence of these minerals can be readily distinguished from one another under the microscope by the characters of the minerals and their relations to the rock mass.

Further, it may be pointed out that olivine, except in the more recent rocks, is found, as a rule, to be more or less altered to, or replaced by, serpentine, quartz, iron ore, carbonates, etc.; augite by hornblende, biotite, chlorite, etc.; and feldspar by quartz, kaolin, micaceous and chloritic minerals, etc.

These changes are so common that it is rare to find in the older rocks original minerals that remain unchanged.

Again, almost every mineral in rocks is found to contain inclusions of other minerals, of glass, liquid and gases, thus vitiating conclusions drawn from chemical analysis of the mineral.

Since our deposits are, in general, associated with altered or metamorphosed rocks, and occur in regions in which thermal waters have been active, the country rock would naturally be more or less changed, and sometimes completely decomposed. In the process of the formation of the ore deposit, it may happen that the ore material will be entirely removed from the adjacent rock, or in this rock there may be deposited ores that never existed in it before, the ore material having been brought from a distance by the percolating waters.

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† Bull. Mus. Comp. Zoöl., 1879, V. 277, 278; Lithological Studies, 1884, pp. 25-29

(*b*) From the above it follows that chemical analyses alone, either of the country rock or of its enclosed minerals, lead to unreliable conclusions as to the source of the ores, as they indicate only what now is in the rocks or minerals, and not what might originally have been there. Hence it is an unphilosophical procedure to build any general theory upon such analyses, unless they are carefully supplemented by thorough and accurate geological study of the region in question.

(*c*) If, by chemical analysis, any accurate deductions are to be drawn regarding the original source of the ores, it seems necessary that we should select those rocks and minerals that are known to be fresh, unaltered and free from any foreign inclusions that would influence the result. Such materials could only be obtained from recent lava flows, recently formed limestones, etc.; for no rock that has been exposed for a considerable length of time to the earth's meteoric agencies can, in the writer's opinion, be said to be in its pristine condition. Most analyses of such rocks fail to include tests for minute quantities of such materials as comprise the more valuable ore deposits, to permit as yet any general conclusion to be drawn concerning the source of all our metals. The nearest approach to any such analyses is in the meteorites, which are unaltered and which in composition and structure are closely allied to certain classes of terrestrial basic rocks. These meteorites are found to contain copper, tin, nickel, cobalt, arsenic, zinc, manganese, chromium, and graphite, and it is probable that more careful and searching analyses would reveal in them and in the lavas other and more precious metals.

(*d*) While it would appear probable that the elements of the useful ores were often originally disseminated through the rocks, particularly the eruptive ones with which they are associated, and subsequently concentrated by the agency of percolating waters, proofs that this theory is correct are yet wanting, the theory resting mainly upon the observed structure of the ore deposits, their association and the alteration of the adjacent rocks, or rather upon the geological conditions observed, than upon any chemical analyses yet made.

§ 6. Most of the work done by the Michigan Survey on the Gold Range was done in the summer of 1890, although I had made some examinations previously. The description below given will, therefore, represent mainly the condition of the work in the range that year.

In giving a brief summary of the facts observed, the attention is called first to Sec. 25, T. 48, R. 28.

(*a*) *The Peninsula Mining Company* has done considerable work in the southwest quarter of the southwest quarter of this section, and has sunk two shafts to the distance of from 40 to 60 feet.

The rock that is worked for gold consists of a granite closely approaching a felsite. This granite has been filled in with more or less secondary quartz which forms irregular strings and patches. It is only occasionally that anything like a vein structure can be seen, and the deposit is much like the deposit of the copper and its gangue in the melaphyrs of Portage Lake. Diorite is found in immediate connection with the granite, and is probably younger than the granite rock, which doubtless has been impregnated with quartz and other materials through percolating waters following the eruption of diorite.

Some free gold was seen, as well as the following minerals, at various points on the property: Quartz, tourmaline, chlorite, dolomite, pyrite, pyrrhotite, calcite, epidote, chalcopyrite, and sphalerite. In the diorite distorted cubes of pyrite were seen which were surrounded by a subsequently formed zone of quartz.

This particular location comes under the head of an impregnation, or replacement deposit, and its metals and associated minerals have probably been collected by the percolating waters from the granite and its associated diorite. It would come under the special head of a dike or mass deposit. formed by the impregnation of a non-fragmental eruptive rock.

(*b*) *Swain's Location.*—N. E. $\frac{1}{4}$ of N. E. $\frac{1}{4}$, Sec. 36, T. 48, R. 28.

At this point the country rock is diorite, which is traversed by a segregated vein of quartz. The diorite adjacent to the vein is schistose and chloritic, the alteration extending into the diorite some two feet on the north side but only a few inches on the south side of the vein.

The vein is quite banded, which for the most part is due to the successive deposition of quartz along the schistose planes of the diorite, leaving some of the undissolved rock between the quartz bands. Part of the banding is due, however, to magnetite arranged in layers or streaks. By the miners the schistose diorite is called slate, and the magnetite, tetrahedrite.

Beside the quartz and magnetite, the vein carried visible pyrite, chalcopyrite, dolomite, feldspar, and tremolite. The tremolite is arranged in stellate aggregations of fine needles or blade-like crystals.

On the same location chlorite and pyroxene occur in small quartz veins.

The main vein is quite regular, but it swells out at one point and tends to pinch out at another.

On the N. W. $\frac{1}{4}$ of N. E. $\frac{1}{4}$ of Sec. 36 some work has been done. Here the vein is narrow and pockety, and is broken up into small, irregular strings. The country rock is diorite with some felsite. The quartz vein has been fractured, and numerous veins of dolomite now cut through it in every direction. The quartz in some places is entirely replaced by dolomite. The country rock is often corrugated along the contact, and now consists of a much decomposed chloritic substance that falls to pieces when struck by a hammer.

(*c*) *The Grummet Location* is found across a swamp to the west of the above, on the N. E. $\frac{1}{4}$ of N. W. $\frac{1}{4}$ of Sec. 36. The vein at this location is found in places to be banded on account of its holding enclosed layers of country rock. At other points it shows a merolitic structure, formed by dolomite, chlorite and quartz. The dolomite replaces the quartz here, as it does at the location above given.

The wall rocks, or at least one of them, is a felsite, which the vein seems in part to have replaced. Felsites later than veins were seen to cut directly across the latter. The wall rock on the Grummet Location is impregnated with dolomite and quartz, which run in narrow seams parallel to the walls of the vein. These seams are sometimes mineralized to a remarkable extent with pyrite. There is a chloritic rock associated with the vein at this place that has a very peculiar structure and jointing. It has been referred both to the diorite and to the felsite. The vein is found close to the south line of the property, and also on the S. E. $\frac{1}{4}$ of N. W. $\frac{1}{4}$.

(*d*) This last locality is known as the *Giant Location.* At this place the conditions are somewhat different. The vein follows the north side of a felsite that cuts the diorite, and appears to have quite well marked walls. The vein also holds interbanded portions of its walls formed by the diorite on one side and the felsite on the other. A short distance to the north of the so called main vein is a segregated mass that seems to replace partly the felsite, but mainly the diorite. The diorite along the walls of the vein is found to be much corrugated and decomposed, and its fragments are enclosed in the vein along with those of the felsite. On the W. $\frac{1}{2}$ of the N. W. $\frac{1}{4}$ of Sec. 36, T. 48, R. 28, the vein follows the contact of a felsite and diorite, and evidently replaces both. There appear to be here two felsites, a black and a brown one, the latter being probably the younger. Here the same general decomposition, as mentioned before, is seen to have taken place along the walls of the vein.

The felsite shows dendritic markings quite sharply outlined, and the vein holds chalcopyrite, pyrite, sphalerite, etc. The rocks seem to show rubbing along the walls, and quartz is deposited in fissures along the sides. While this vein is probably a segregated vein, it approaches in some respects a fissure vein.

(*e*) The next workings west are on Sec. 35, E. $\frac{1}{2}$ of N. E. $\frac{1}{4}$. The work is carried on by the *Lake Superior Gold Company.* The vein is narrow, but contains considerable gold. It has diorite and felsite for its walls, although towards the west side of its workings the felsite seems to cut the vein, as if the former were younger. This vein is not well marked, but is broken and quite capricious. Several small, string-like veins also occur here, some in diorite and others in felsite.

(*f*) The next property west is that of the *Michigan Gold Mining Company*, situated on the N. W. $\frac{1}{4}$ of the N. E. $\frac{1}{4}$, Sec. 35, T. 48, R. 28. The country rock here is diorite, but felsite dikes occur cutting the vein. There is little or no felsite directly associated with the vein here, except at its extreme west end.

The diorite walls are usually well marked and are decomposed to a chloritic material. The vein is quite persistent on this property. In places it holds "horses" of diorite, as for example at the No. 2 working shaft, where one of these enclosures extends from the bottom of the workings to the surface. This "horse" is quite well impregnated with mineral matter, as is also the decomposed diorite forming the walls of the vein. The walls tend to contract and expand so as to give a somewhat lenticular form to the vein, although that feature is not as noticeable here as it is at some of the other localities on the Gold Range. A great deal of free gold has been taken from this mine. The only mineral found here, that has not been observed at other mines, is molybdenite. The vein has the same banded structure that has been described elsewhere as occurring in the veins of the Gold Range.

(*g*) On the N. E. ¼ of N. W. ¼, Sec. 35, T. 48, R. 28 is the property of the *Superior Gold Mining Co.* The country rock here is diorite altered along the walls to a chloritic slaty material. The vein is cut by felsite dikes, one of which is near the shaft and another near the Michigan Company's line; it is here split into two parts, the lesser portion being to the south.

The vein has a merolitic structure in places, and is somewhat capricious, swelling out and in to a marked degree. Dolomite with tremolite and actinolite replaces the quartz. The materials of the merolitic structure are calcite, chlorite, and wall rock, with sometimes a little quartz and fibrous tourmaline, chalcopyrite, pyrrhotite, and pyrite. The wall in places shows slickensides, and the crushed appearance of the country rock may be partly due to rubbing, although for the most part it is probably due to the action of water percolating along the joints. Free gold was also seen in this vein.

(*h*) The Mockler brothers of Ishpeming explored on the S. W. ¼ of S. W. ¼ of Sec. 35, T. 48, R. 28. Granite and diorite form the country rock. The character of the vein found on this property is very much like that of the vein at the Superior, and the fibrous tourmaline is observed to occur in it. The vein seems to follow along the contact between the granite and diorite for some distance, when it shoots off into the diorite. The diorite itself is quite schistose; the foliation runs about parallel to its junction with the granite. All of the veins in the Gold Range vary much in width; some are in places only a few inches, and then swell out to a width of four or five feet, and some are even eight feet wide.

(*i*) At the *Ropes Mine* the country rocks are serpentine and diorite. In this mine the veins are lenticular and partake of many of the characters of gash veins, although they may readily be called segregated veins, as in part they appear to be such. The custom here has been to search for new veins as each old one was exhausted. The veinstone, as in the other mines, is principally quartz and the associated country rocks in the vicinity of the veins are usually more or less impregnated with gold, so much so that they are often mined and sent to the mill.

In the Gold Range none of the veins except possibly that of the Michigan Company appear to be persistent, but they seem in the main to be segregated forms which have in many cases been thought to be the same vein. Veins of the character of those in the Gold Range, as a rule, do not support an expensive plant or a large force. Success comes rather from careful and economical working on a small scale, with the use of a general custom mill for all mines from which it is accessible, instead of the establishment of an independent mill for each vein.

(*k*) Some assays of various veinstones have been made for the Michigan Survey, to ascertain if they contained gold or silver in paying quantities. In each case there was not selected an average sample, but the most promising material for gold and silver that could be found. No. 866 was assayed at Mr. Wright's office and the rest by Mr. F. F. Sharpless of the Michigan Mining School.

Locality.			Number.	Oz. of gold per ton.	Oz. of silver per ton.
Section.	T. (north.)	R. (west.)			
15	48	25	866	trace	
N. E. ¼ of 25	48	28	11,948	0.05	
S. W. ¼ of 14	47	43	14,140		1.35
S. W. ¼ of 2	40	30	14,177 (a)		
S. W. ¼ of 2	40	30	14,177 (b)	trace	
S. E. ¼ of 2	40	30	14,182	trace	
S. E. ¼ of 2	40	30	14,182		

CHAPTER VII.

PALEOZOIC SYSTEM.

POTSDAM PERIOD.

§1. The rocks of the Azoic system were still subject to the same denudation by frost and rain, and by the beating of the waves after that formation had been completed, that the different members of the formation had been subjected to before the entire system was complete. That is, there were deposited about the Azoic rocks mud, sand and shingle, in like manner as such materials are being deposited on our lake shores at the present time. This detritus, on consolidation, has formed a series of shales, sandstones and conglomerates, which overlie or abut against the Azoic rocks, and are formed out of the debris of the latter. These sandstones form in Michigan the base of a new system of rocks known as the Paleozoic, or ancient life, from its containing the earliest authentic remains of animal life. The sandstones are generally considered to be the equivalent of the Potsdam sandstone of New York.

(*a*) South of Carp river this sandstone can be seen lying against the Azoic quartzites and formed out of their debris. The Marquette sandstone quarries are in this Potsdam sandstone, and at the base of the quarries may be found conglomerates made up of the underlying Azoic quartzites, diorites, argillites, schists, etc.

In Marquette can be seen, on the west side of Champion street, some rounded diorite and schist knobs that have been polished and grooved by glacial action. A matter of special interest here is the finding of small clasolites of the formerly overlying Potsdam sandstone which has filled the cracks in these rocks, that formed bosses or little knobs on the shores of the old Potsdam sea.

The Potsdam sandstone is found overlying much of the serpentine of Presque Isle where the basement conglomerate is well exposed, although that conglomerate has subsequently been much altered, apparently, by heat and water. The same sandstone occurs further north on the shore, and on some of the islands that overlie the Azoic granite, which has been decomposed for some distance below the base of the sandstone. This decomposition is seen to extend to the boulders of granite and other rocks in the basement sandstone and conglomerate. These changes unquestionably have occurred since the sandstone was deposited, and the percolating waters are apparently the cause of the decomposition. The sandstone extends, with greater or less continuity, along the shores of Lake Superior, around Keweenaw Bay and Keweenaw Point. On Partridge Island clayey or sandstone fragments occur abundantly in the Potsdam sandstone itself. They may be fragments of another sandstone formation, or they may be water-worn masses of clay, etc., derived from the Potsdam itself, or from clay beds resting on the Azoic rocks. The writer has seen similar clay deposits being formed on the Bay of Fundy in the vicinity of St. John.

Potsdam sandstone is quarried to a considerable extent at various points in northern Michigan, chiefly at Marquette and Portage Entry. It makes a very handsome building stone, and one for which there is ready sale.

Analyses of the Portage Entry red sandstone and of the Marquette brown sandstone have been made by Mr. F. F. Sharpless with the following results:

	Portage Entry No. 12,045.	Marquette No. 11,993.
SiO_2	82.60	77.18
Al_2O_3	8.32	9.69
Fe_2O_3	0.28	3.20
CaO	0.55	0.26
MgO	0.18	1.48
MnO	0.13	----
Na_2O	----	0.18
K_2O	6.49	4.67
P_2O_5	0.05	0.21
SO_3	0.31	0.23
H_2O	0.99	2.90
	99.90	100.00

Tests of the crushing strength made by Dr. R. G. G. Moldenke gave the following results:

No. 12,045 (block 4″x 4″x 3″) 6,350 lbs.

No. 11.993 (block 1¾″x 2⅛″x 1″) 3,800 lbs.

Gen. Gillmore reports that the average of five tests of the Marquette stone crushed on the bed gave a crushing strength of 6,259 lbs. to the square inch, and three tests of its strength on the edge gave 5,377 lbs. per square inch; it is therefore probable that No. 11,993 is not a typical but an imperfect stone, something that the appearance of the samples indicates.

Tests made by Mr. F. W. Denton show that the ratio of absorption is 1 to 19 for the Portage Entry stone, and Gen. Gillmore's tests for the Marquette stone gave a ratio of 1 to 20.

(*c*) The Potsdam sandstone was evidently formed on the shores of a body of water accessible to ocean tides, as it shows ripple-marks, suncracks, rain-drop impressions, and mud-flows, which indicate conditions that are only known to exist in localities where the alternate ebb and flow of the tides occur.

(*d*) During the time of the deposition of this sandstone, volcanic activity commenced again, and the central portion of Keweenaw Point is found to be composed of alternating lava flows, sandstones and conglomerates, deposited upon the tide-washed sinking shores of the sea. The intermittent volcanic activity ceased for a while after the main range of Keweenaw Point was formed, leaving time for the formation of a broad belt of sandstone and conglomerate; but again recommenced, forming the basaltic rocks exposed along the northern side of Keweenaw Point at Eagle Harbor, Agate Harbor, Copper Harbor, and elsewhere.

In connection with these lava-flows from fissure eruptions that were of a basaltic character, there was also extravasated much volcanic material of a trachytic and rhyolitic nature, the debris of which makes up the chief portion of the interbedded sandstones and conglomerates. These occur in the form of intrusive dikes, bosses, etc.

(*e*) The basaltic rocks forming the southeastern range of Keweenaw Point, known as the Bohemian Mountains, were considered by Foster and Whitney to be intrusive masses erupted subsequently to the formation of the main deposits of this region. Irving, however, considered them to be ordinary flows, like the rest of the lava-flows of Keweenaw Point. He does not advance any special proof of this theory, while the phenomena presented by him, as well as by Foster and Whitney, appear to be more in accordance with the view that they are later eruptive masses, as held by the last named observers. However, the question is still an open one.

(*f*) The lava-flows are known to be such, as pointed out by Foster and and Whitney, and later by Marvine and Wadsworth, by their baking or indurating, or hardening the underlying rock; by their sending dikes and tongues down into the rocks; by their having caught up fragments of the underlying rock; by their crystalline structure being best developed below the center of the flow; by their having no effect upon the overlying conglomerate, while the debris of the lava is to be found in the base of the conglomerate; by the overlying conglomerate and sandstone filling cracks in the underlying lava-flow, etc.

(*g*) The thinner basaltic lava-flows were cooled quickly, so that they contained much glass, which was readily decomposed by the percolating waters. In their altered condition they now form rocks known to the geologists as melaphyrs, but which are locally called amygdaloids.

The thicker flows formed heavy beds which cooled more slowly, became more crystalline and were less easily affected by the percolating waters than the thinner flows. These heavy flows, owing to their alteration, now form rocks by geologists named diabases and gabbros, but locally called traps and greenstones. All these now different rocks were once lavas of the same chemical constitution, differing only in structure and in those varieties of crystallization and mineral constitution that result from slow or rapid cooling.

(*h*) These flows must have taken place over the gently sloping, tide-washed shores of a sea, whose shore was gradually, or, it may be, at times abruptly sinking, so that the flows and their detrial deposits accumulated at about the same rate as the shore sank, making the shore line approximately constant. This must have been the case or the lava-flows and conglomerates would have been more irregular, less constant, would have covered a more limited area, and would soon have been built up beyond the reach of the waves.

Owing to the natural irregularities of a lava-flow, and of the resulting inequality of the sedimentary deposits, it is to be expected that some inequalities in thickness of both formations should exist, and that sometimes one or the other should be wanting. For instance, if a portion of the lava was raised above the sea, that portion would not be covered by either sandstone or conglomerate, but only by its own decomposition products, and that too only when they were not carried away by the rain. Hence it would happen that the material between two flows would be marked at one point by a conglomerate, but elsewhere only by a thin seam, or else the two flows would be interfused.

It also frequently happened that a comparatively short time existed between two flows. In such a case little or no conglomerate could form between them, and as the latter flow fused again the top of the earlier flow, the two became united into one mass, so that it is difficult to ascertain where one begins and the other ends.

(*i*) That the copper bearing rocks belong to the same age as the Eastern sandstone, as here stated, is far from being admitted by many geologists, who consider that the above lava flows form a distinct but older series, against which the Eastern and Western sandstones were laid down. In this connection it may be said that Walcott[*] is mistaken in crediting Irving with the first use in 1883 of the terms Eastern and Western sandstone, as they were used by myself in the same sense in 1880, and subsequently, in contradistinction to the copper bearing rocks, or the traps with their interbedded sandstones and conglomerates.[†]

§ 2. The age of the Eastern sandstone has been proven to be lower Silurian, and probably Potsdam, by the work of Mr. W. L. Honnold. A limestone west of L'Anse in T. 51, R. 35, has been described in Jackson's Report (1849, pp. 399, 452), Foster and Whitney's Report (part I., 1850, pp. 117-119), and in Rominger's Report (1873, I. part 3, pp. 69-71), and the limestone considered from its fossils to be Trenton or some adjacent lower Silurian strata. It was inferred by Jackson that the limestone underlies the sandstone, but by the other observers that it overlies it, although no direct contact was seen.

Excavations made by Mr. Honnold's party and reported by him have exposed the contact of the two formations, and show that the two form a synclinal or oblong basin-shaped fold, with the limestone overlying and in direct contact with the sandstone. The existence of this fold in the sandstone, as well as in the limestone, removes the difficulty previous observers have had in reconciling the obviously tilted limestone with the supposed horizontal sandstone, and proves that the Eastern sandstone exposed here is of lower Silurian age, and older than this limestone.

At the point of contact of the two formations, exposed by excavation, the sandstone and limestone appear to be conformable, and they are seen constantly to agree in dip and strike. The contact between the two formations is abrupt, without any beds of passage, although the upper layers of the sandstone contain considerable carbonate of lime and magnesia, and the lower layers of the limestone much silica.

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[*] Correlation Papers. Cambrian Bull. U. S. Geol. Sur., No. 81, 1891, pp. 252, 335.

[†] Notes on the Geology of the Iron and Copper Districts of Lake Superior, 1880, pp. 98, 107, 108, 110, 116, 121, 122; Proc. Am. Assoc. Adv. Sci., 1880, XXIX., p. 429; Proc. Bost. Soc. Nat. Hist., 1880, XXI., pp. 92, 94, 103.

These observations are considered to be confirmatory of the commonly received view of the Potsdam age of the Eastern sandstone; while the contorted state of the sandstone which extends at least a mile and a half west from the limestone locality, may have weight in deciding the relative age of the Eastern sandstone and the copper-bearing rocks.

An analysis has been made by Mr. F. F. Sharpless of a limestone, No. 13,462, from this locality, and is given here in connection with that of another supposed Trenton limestone, No. 14,413, from Sec. 36, T. 37, R. 27, W.

No. 13,462.		No. 14,413.	
SiO_2	2.57	SiO_2	10.11
Al_2O_3	0.41	Al_2O_3	2.10
Fe_2O_3	1.19	Fe_2O_3	0.37
$CaCO_3$	49.76	CaO	25.92
$MgCO_3$	41.37	MgO	18.75
K_2O	Undetermined.	K_2O	0.88
Na_2O		Na_2O	0.86
SO_3		CO_2	36.13
P_2O_5		H_2O	0.98
H_2O		TiO_2	Undetermined.
		P_2O_5	
		SO_3	
		MnO	
		Organic matter	
	95.30		96.10

THE NORTH TRAP RANGE.

§3 It here becomes necessary to take up the relation of the lava-flows, with their interbeded conglomerates, to the Potsdam sandstone on the east, a matter of great scientific and economic interest that has given rise to much discussion, which is liable to continue for many years to come, until the whole truth shall be known.

(*a*) In the report of Foster and Whitney the Eastern sandstone was considered to have been once continuous with the sandstone that lies to the west of Keweenaw Point, but it was thought that the two parts had been separated by a fracture or fault plane that extended along the entire southern side of Keweenaw Point. This fault allowed the sandstone on the east to remain horizontal, while the lava-flows on the west were tilted up at the same angle that they at present have, and the overlying Western sandstone was subsequently worn away. The sandstone east of the fault line was said either to lie horizontally, or to dip to the southeast.

(*b*) Later, attention was called to certain observations made along the line of the fault, especially at the Douglass Houghton falls. These observations caused the lava-flows and their imbedded sedimentary rocks to be considered as an older geological formation than the Eastern or Potsdam sandstone. The lavas were said to form an old sea-shore bluff on the Potsdam sea, and the sandstone was laid down horizontally, abutting against the cliffs, and formed from their water-worn debris. Various other opinions have also been advanced to which it is not necessary to refer here.

(*c*) In 1879 the present writer made an examination of the formations at the points at which, on the Douglass Houghton and Hungarian rivers, the Eastern sandstone comes in contact with the lavas, or, as they are now commonly called, the copper-bearing rocks or Keweenawan series. He found that the sandstone instead of lying horizontally, dipped gradually or irregularly toward the northwest, and that, instead of abutting against the copper-bearing rocks, it was overlain by the latter, and the two were interbedded.

(*d*) Later, the correctness of these observations was denied by Chamberlin and Irving, who upheld the view of the greater age of the copper-bearing rocks, but moved the supposed sea-shore cliff from its former supposed locality and placed it elsewhere. Subsequently the question was taken up again by Irving and Chamberlin in defence of the view that the copper-bearing rocks are older than the Eastern sandstone. If, however, one will take their published observations, together with the diagrams in their later work, he will see that their preceding observations are discredited, and that they fully sustain the correctness of my former statement, that the sandstone dipped under the copper-bearing rocks instead of being separated from them by a vertical fault or an old sea bluff. They denied, however, the presence of a general northwesterly dip of the sandstone. The result was that on the main point at issue they showed that I had been correct, *i. e.*, that the sandstone did underlie the copper-bearing rocks, and the main question was then transferred to one of interpretation: Do the lavas overlie the Eastern sandstone on account of their having flowed over them in the form of a molten lava, as I have claimed, or have the lavas been thrust up over the sandstones, through the motion of an older solid mass along an oblique fault-plane, as last held by Irving and Chamberlin?

(*e*) That the Eastern sandstone does dip to the northwest and pass under the traps has been clearly shown by the Michigan Survey, and is so plain that no one who has been on the ground and seen the evidence can deny it truthfully. The overlap of the trap on the sandstone can be seen at the Douglass Houghton Falls. As to whether the overlap here is due to the lava flowing over the sandstone, or to its being thrust over it by a reversed fault, various opinions exist; but concerning the facts all who have examined the location now agree.

§ 4. Studies have been made by the Michigan Survey along the line between the Eastern sandstone and the copper-bearing rocks for the purpose of rectifying the boundary and also of ascertaining if possible the relations of the two series.

(*a*) In this examination it was observed that on the north side of Bete Gris bay, on Sec. 25, T. 58, R. 29, the sandstone varies much in strike, owing to its folded condition. It has an irregular dip S. E., varying from 50° to 70°, and even vertical. In one place a synclinal fold was observed that has a dip N. W. 15° and S. E. 50°. The sandstone here contains pebbles that seem to be melaphyr, apparently derived from the copper-bearing rocks. On section 26, T. 58, R. 29, the dip is more uniform and is S. E. 35°. It is here almost in direct contact with the melaphyr, only three or four feet of loose soil covering the junction between it and the latter. The sandstone at this place contains pebbles of the melaphyr. With the adjacent melaphyr are found interbedded conglomerates characteristic of the copper bearing rocks, showing that at this point the series is the same as further south. Whether the Bohemian Mountains are erupted along a fault line, as claimed by Foster and Whitney, or are interbedded, as claimed by Irving, no data have been obtained by the Michigan Survey beyond those mentioned above, which go to show that if the

Bohemian Mountains are later eruptions, they must *here* have been extravasated within the copper-bearing rocks and not along the line of junction between these rocks and the Eastern sandstone.

(*b*) On the north side of Gratiot Lake, in Sec. 5, T. 57, R. 30, the sandstone apparently dips vertically or is tilted slightly away from the melaphyr. Here the strike varies rapidly and the folding is much like that at Wall Ravine on section 20, T. 56, R. 32. The contact was not seen at this place, as a drift surface about 25 feet wide intervenes between the sandstone and the melaphyr.

The next place where dips are seen is on Sec. 18, T. 57, R. 30. At the N. W. corner and about 100 paces south of it is melaphyr, then for about 100 paces drift intervenes before the first sandstone is seen in the bank of a small stream. The strike is N. 65° E., and the dip is northwesterly 80°. The melaphyr trends east and west and dips N. 25°. One hundred and fifty paces below the first sandstone outcrop is a second that is horizontal, or has a slight dip to the south.

On the N. W. ¼ of Sec. 14, T. 57, R. 31, the sandstone is seen about 200 paces from the melaphyr, striking N. 20° E., and dipping westerly 80°. Five hundred paces down the stream from the contact, the dip is northwesterly 12°, and one hundred paces further south it seems to be horizontal. The conditions here appear to Mr. Seaman much as they do along the Douglass Houghton and Hungarian rivers, although the unconformity is more strongly marked here.

On Sec. 22, T. 57, R. 31, sandstone is seen about 250 paces south of the melaphyr. The dip is S. E. 16°, 28°, and 45°, the nearer the contact the steeper the dip.

On Sec. 21, T. 57, R. 31, the sandstone is seen with a vertical dip about 500 steps down stream from the melaphyr.

On Sec. 20, T. 57, R. 31, the sandstone 100 paces from the melaphyr stands also in a vertical position.

Other places have been observed where the two series were seen in close proximity, but no dips were taken. From these observations Messrs. Seaman and Lane, who made them, think that the rocks occupy the same general relations all along the contact line, the sandstones dipping towards, or away from the Keweenaw series, according as the fault cuts the folds in the sandstone, or has bent the strata up or down.

(*c*) At Wall Ravine the sandstone is folded, the strike varying from N. 25° E. to N. 76° W. and the dip from about 40° to vertical.

At several places on Sec. 20, where streams cross the contact, the sandstone is seen to stand nearly vertical or to dip towards or away from the melaphyr, as the case may be.

On Sec. 19, in the S. E. ¼ of S. E. ¼, the sandstone at contact dips N. W. 50,° while 150 paces down stream away from the contact the dip is S. E. 50.°

Near the center of Sec. 30, T. 56, R. 32, the sandstone was found to dip northwest at an angle of 35.°

(*d*) At the Douglass Houghton Falls, Sec. 36, T. 56, R. 33, the sandstone dips at an angle of about 20° and passes under the melaphyr and diabase. This underlying sandstone can be followed for about 59 paces under the traps on the north side of the ravine. On the south side melaphyr was found overlain and underlain by sandstone and argillites.

(*e*) On the Hungarian river, Sec. 11, T. 55, R. 33, the sandstone dips northwesterly at an angle of from 5° to 15,° and, as before, passes under melaphyr and diabase. On Sec.s 21 and 22, T. 55, R. 33, the fault line runs east and west for at least a mile. The sandstone is so much broken that the dip could not be obtained.

(*f*) On Sec. 6, T. 54, R. 33, the strike of the fault line is about north and south and the sandstone at contact dips W. at an angle of about 50° to 55.° At this point excavations showed the sandstone to be rubbed and grooved, giving evidence of a fault line. About two feet of broken decomposed material (a fault breccia) was found at the contact between the sandstone and melaphyr.

On Sec. 12, T. 54, R. 34, near the east quarterpost the sandstone was observed to dip S. E. at an angle of 45° to 75.° On Sec. 14, T. 54, R. 34, the sandstone stands vertical and strikes N. 55° E. That on Sec. 12 strikes N. 25° E.

On Sec. 12 the sandstone was observed to cut across the beds of melaphyr, diabase and conglomerate, which reappear 500 paces beyond. This may be accounted for by the numerous cross faults that cut the formation all along the copper-bearing belt; or it may be a bay of sandstone lying in or on the traps. The former seems to me the more likely explanation since the general strike of the lava flows swings more to the westward in this vicinity.

On Sec. 22, T. 54, R. 34, the sandstone dips east 60° and strikes N. 18° E.

On Sec. 32, T. 51, R. 37, the sandstone was observed to be much jointed and broken; the dip is uncertain, but seems to be slightly northwest or else horizontal.

On Sec. 24, T. 50, R. 39, the dip is about horizontal 400 paces from contact, while about 150 paces south of contact the dip is given as vertical.

On Sec.s 31 and 32, T. 50, R. 39, the dip varies from 17° to 55,° increasing toward the melaphyr. The sandstone was not seen nearer than 500 paces from the melaphyr.

(*g*) On the east line of Sec. 2, T. 49, R. 40, the sandstone was seen in the Ontonagon river lying about horizontal. Near the center of the section it is seen to dip south. The continuous change in dip and strike in the sandstone is quite noticeable all along the fault line, and different flows are brought into contact with the sandstone by this irregular line, so that one appears to cross rapidly from higher to lower or from lower to higher members of the copper-bearing rocks. This is especially marked between Houghton and Lake Linden, particularly in the vicinity of the Hungarian river.

The copper-bearing rocks were followed westward to T. 48, R. 45, with but little result so far as the determination of their relation to the Eastern sandstone is concerned.

(*h*) The general result of the above observations made along the contact line by the aid of numerous excavations, is that on the Douglass Houghton and Hungarian rivers, as well as on Sec. 20, T. 56, R. 32, the sandstone does dip gently toward the lavas, and finally passes under them with an increasing dip; that the junction appears to me not to be a fault junction but that of a lava flow upon an underlying soft sand and mud forming irregularly truncated layers on a sea beach, while others consider it a fault line.

Along the line of contact to the north on the St. Louis location and in Wall Ravine, as well as south of Portage lake, proof of distinct faulting could be obtained, which sustains the fault claimed by Foster and Whitney, Irving, and others. Along the immediate line of the Douglass Houghton Falls contact few signs of a fault exist, but in the copper-bearing series above this contact and just below the falls can be seen several fractures that show evidence of motion of their sides. This would indicate a faulting here.

The fault plane, wherever observed along the line of contact, showed that the overhanging wall was on the side next the copper-bearing rocks, or that if these rocks were older than the sandstone, the fault is a reversed and not a normal one.

This mode of faulting with a strong eastward thrust is the one assumed by Irving. This is based on the contortion of the sandstone and its deep vertical dip seen at Wall Ravine and northeastward and in some other localities. If a normal fault took place, the same bending would naturally be caused by the sinking of the wider segment of the traps and their pressing against the sandstone, while the phenomena at Lac la Belle are easily explained if the Bohemian Mountains are a later protrusion.

(*i*) I would then consider from the present evidence that the Eastern sandstone underlies the copper-bearing rocks, and that the first lava of that series flowed over the Eastern sandstone, which is older than the copper-bearing or Keweenawan series. Subsequently a fault line or fissure was formed, running near what is now the point of contact of the sandstone and lavas, sometimes exactly at that point, sometimes on the lava side, and probably sometimes on the sandstone side of it. Along the fissure it is probable that a normal fault occurred, along which, by the slipping down of the hanging or wedge shaped side, the sandstones and their interbedded lavas were more or less bent downwards or contorted, as they are now found to be. This normal faulting accounts for the fact that sometimes the lava and sometimes its associated conglomerate is brought into contact with the Eastern sandstone along the fault line. It is to be remembered that in almost all faults there is more or less rubbing back and forth, although the final result of these varied motions is the production of a reversed or normal fault, according to the direction in which the greatest amount of motion took place.

This view would explain most of the difficulties that geologists have had in understanding this series of rocks, especially if it should be shown that the lava-flows came from the west side of Keweenaw Point, instead of from the Keweenaw Bay or east side, as that would only require cut-off remnants of the edges of the lava-flows to be removed by denudation on the latter side.

Should the theory of a reversed fault be proved to be the true one, then the view of Foster and Whitney concerning the relations of the copper-bearing rocks to the Eastern and Western sandstones would appear to be more correct than that of Irving, while a normal fault would be consistent with the theory that the copper-bearing rocks are of Triassic age.

(*j*) I do not consider that the lithological evidence employed to show that the latest melaphyrs and diabases of the Azoic system are the same as the copper-bearing traps, has any bearing upon the question of the relative ages of the sandstones and the copper-bearing rocks, since every one who regards these latter rocks as belonging to the sandstone series, places them at the base or only part way up in that series. In this case, the finding of pebbles of the melaphyr in the sandstone shows only that at this point the sandstone is younger than the melaphyr, and may belong to the latest or highest member of the series. Similar dikes of melaphyr and diabase are found in almost every formation up to the Tertiary, and lithologically the more modern forms are undistinguishable from these old Azoic dikes.

The chief point seems to be: Do the traps at the Douglass Houghton and Hungarian Falls overlie the Eastern sandstone as flows or as an overthrust or reverse fault? This apparently can be determined only by excavating to a point where the undecomposed rock can be found, so that the special kind of contact that the two series make with each other can be seen.

Some more decided conclusions may be draw from other evidences, like finding pebbles of the copper-bearing rocks in the Eastern sandstone. Acid pebbles of the conglomerates I have found abundantly at both the Douglass Houghton and Hungarian locations, but I have never found there but one that was apparently melaphyr, and that only recently, although they have been frequently sought for. Again, the Eastern sandstone may contain two or more sandstones of different ages, a view that at the present time may perhaps be considered as the most probable explanation of the various evidence and opinions.

THE SOUTH TRAP RANGE.

Sec. 5. On Sec.s 1 and 12, T. 49, R. 36, and Sec. 6, T. 49, R. 35, is located Silver Mountain. It is composed of interbedded lava-flows, of which at least ten were made out with more or less certainty. These flows dip to the northwest at an angle of from ten to sixteen degrees. The nearest sandstone found was two miles away. This has a slight dip to the northwest. On Sec.s 29 and 30, T. 47, R. 37, a series of melaphyr flows were observed dipping at a low angle to the north, or a little west of north, the angle of their greatest inclination being from 15° to 20°.

The flows are interbedded with sandstone which holds fragments of the melaphyr. A felsite dike also cuts through the beds.

Similar lava beds are found on Sec.s 25 and 35, T. 47, R. 38, which dip at a low angle, 9° to 16°, north or a little west of north; while at the falls on Sec. 1, T. 46, R. 39, the flows dip from 9° to 20°, the principal dip being to the north, at an angle of 14°. About half a mile north of this point, the sandstone is seen in the bed of the Ontonagon river. Outcrops of the same old basaltic rocks occur on Sec.s 8, T. 46, R. 39, which show a very low inclination, while the sandstone crops out near the north line of the section.

The most important observations were made in Sec.s 2, 9, 10, 11, 12, 13 and 14, T. 46, R. 41, where the sandstone was found overlain by some of the lava-flows. The sandstone here is found in contact with schists, presumably of the Archæan, or Azoic, age. The base of the sandstone is of a conglomeratic character, composed of rolled pebbles of quartz cemented by an argillaceous matrix formed from the debris of the underlying steeply inclined and contorted schists. This sandstone dips northerly at an angle of from 12° to 14°, often less, its strike being S. 60° E.

The conglomerate passes into a coarse reddish sandstone which can be traced in pits and exposures northwesterly, where the same coarse red sandstone is seen to pass up into a fine grained indurated sandstone or quartzite, which in its turn passes into a fine-grained indurated argillaceous schist and chert. This indurated zone is in immediate contact with the overlying lava flow of the South Trap Range. The structure here is apparently that of a series of flows arising along a pipe or fissure, and excavation shows the remains of the solidified neck with the downward bent sandstone or schist strata, together with the strong induration produced by the overflowing lava. Some features were seen here to indicate that in the bed of the river a younger sandstone had been deposited, making it probable that there were two different formations here, one older than the lavas and cut by them, and the other younger and containing the debris of both. This point has been considered under the Holyyoke formation.

(*b*) The relations of this lava to the Eastern sandstone have been mistaken by previous observers, as the following extracts will show. The first to call attention to this locality were Messrs. Brooks and Pumpelly, who say: "In the center of the northwest quarter of Sec. 13, T. 46, R. 41, the Silurian sandstone was found exposed in cliffs 50–60 feet high. The strata are horizontal, or at most have a barely perceptible tendency to a northerly dip. About 150 steps from the base of this cliff, there are outcrops of Laurentian schists whose bedding trends N. E. toward the cliff of horizontal sandstone, and dips 45°–60° S. E. The nearest outcrop of the Cupriferous series is in the S. E. corner of Sec. 5, about four miles distant. It is a characteristic amygdaloidal melaphyre, whose bedding planes strike nearly E. and W., and dip 50° to N."*

(*c*) These gentlemen were followed by Irving, who says: "The exposures on the west bank of the Ontonagon, in the northwest [east ?] part of T. 46, R. 41, W., are of especial interest on account of the evidence they offer in proof of unconformity between the Eastern Sandstone and the Keweenawan. * * * The sandstone is horizontally bedded, showing in a south-facing cliff 60 feet high and 350 feet long. It is reddish, very coarse, and composed almost entirely of rounded grains of quartz. One hundred paces from the foot of this cliff are reddish schists trending northeast and dipping 45° to 60° S. E. Seven hundred paces northeast [west ?], near the southeast corner of section 11, is a small ledge of a dark brown, weathered, medium-grained diabase, of the Keweenawan type, while beginning in the northeast [west ?] part of the same section, and running thence westward through sections 9 and 10, and terminating in the southeast $\frac{1}{4}$ Sec. 5, is a series of exposures of a fine grained, greenish-gray diabase pseud-amygdaloid, with chlorite pseud-amygdules." †

(*d*) The observations of Messrs. Seaman, Lane and myself show that in some way the dip of the lava-flows as above given is erroneous, as they in reality dip at an angle of about 12° to 14°, instead of 50°.

To summarize, it may be said, that the observations of the Michigan Survey go to show that the lava-flows of the "South Trap Range," east of Lake Gogebic, do not dip at a high angle, as has been generally asserted, and further that the Eastern sandstone is not horizontal, as has also been generally stated, but that the two dip at a low angle, generally 5° to 20°. These observations also indicate that the Eastern sandstone, or the sandstone that previous observers have called the Eastern, or Potsdam sandstone, and the lava-flows of the South Trap Range are one formation, and are as conformable as eruptions of lava can be with a cotemporaneous sedimentary deposit.

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* Am. Jour. Sci., 1872 (3), III, 431

† Copper Bearing Rocks of Lake Superior, 1883, p. 203.

(*e*) West of Gogebic lake, Messrs. Seaman and Lane found the lava-flows to dip at a much higher angle, to-wit: 35° to 80°.

The conglomerate described by Van Hise, * as proving that the Eastern sandstone was made up of the debris of the copper-bearing rocks, was found to be apparently a modern drift deposit, although some pits to the north contained a sandstone.

(*f*) The lithological characters and the associated rocks appeared to be the same in the copper-bearing rocks west of Lake Gogebic as in those east of the lake, and therefore the two were considered to be the same formation, and the difference in dip explained on the supposition of a fault along the line of Lake Gogebic.

An isolated knob of porodite was seen on S. 23, T. 47, R. 43, and veins of dolomite, galenite and sphalerite on Secs. 13 and 24 of the same township.

CHAPTER VIII.

VEINS AND COPPER DEPOSITS.

§ 1. Beside the fault before mentiond on the eastern side of the North Trap Range, numerous fissures cross the range instead of running longitudinally with it, and more or less faulting occurs along these fissure lines. Portage lake lies in a trough excavated along one of these fissures, while many of the others are filled with vein matter which has been mined to a greater or less extent. These fractures and fissures, with faulting, that run across Keweenaw Point, probably were developed subsequently to the formation of the longitudinal fault or faults, if more than one such fault shall later be proved to exist. Should such be the case it would account for part of the assumed thickness of the beds.

(*a*) The before mentioned fissures seem to have been formed by powerful movements of different parts of the rocks that caused the cross fracture and dislocation of the latter. The movements were repeated from time to time, causing a rubbing, grinding, breaking and polishing of the parts adjacent to the fissures. After the main fissures had been formed, the subsequent movements would not cause any very extensive secondary breaking of the compact and heavy beds of diabase and conglomerate, but in the soft and scoriaceous melaphyrs the fracturing would be much greater, so that the parts adjacent would be much broken. During the time of the fracturing, and subsequently, these fissures served as channels for the chemically active waters, which also percolated through the adjacent rocks. In the scoriaceous and easily decomposable melaphyrs the veins were widened by the decomposition of the adjacent rock, but in the coarsely crystalline and heavy diabases as a rule, the same effects were produced either not at all or only to a limited extent. The sandstones and conglomerates, being composed principally of trachytic and rhyolitic material, are much less affected by percolating waters than the basaltic rocks, hence the fissures are not generally widened in them, especially if they are in thick beds. At the time when the percolating waters were acting in the rocks adjacent to the fissures they were also working in the rocks everywhere upon Keweenaw Point.

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* Tenth Annual Report of the U. S. Geol. Survey, 1891, p. 455, 456.

(*b*) In many localities the evidence is strong that the percolating waters were hot, while in others, as remarked by Marvine, no sign exists that they were above the temperature of the waters of the present day. These waters percolated through the rocks with more or less readiness, causing a greater or less alteration and decay, while the substances they took up were deposited in any fissures, cells or other open spaces that existed in the rock, or else portions of the rock were dissolved out and their places refilled. This is strikingly seen in the conglomerates, like the Calumet and Hecla, in which pebbles of the easily decomposable melaphyr have been partly or entirely removed and their places filled with copper or some other minerals.

(*c*) Beside copper, the deposited minerals are mainly quartz, calcite, epidote, laumonite, prehnite, delessite, chlorite, datolite, analcite, orthoclase, apophyllite, etc. All, or nearly all, of the materials that fill the crevices, cells and other places in the lavas and conglomerates apparently were derived from the decomposition of the lavas themselves, and the course of the waters carrying these materials in solution seems to have been downward. The fissures that form the veins were filled at the same time and by the same agencies as those that acted upon the rocks, and the materials in them likewise appear to have been obtained from the adjacent rocks themselves. In the narrower portions the veins were often filled with vein matter proper, but in the wider portions the veins are often composed of broken up masses of melaphyr, etc., cemented by vein matter.

(*d*) In the veins the copper is found intimately mixed with the gangue, or in sheets or irregular masses. In sheet form the copper extends downward or has its sides approximately parallel with the vein. Oftentimes the sheet divided, and held between its parts some of the gangue or melaphyr. It is also not uncommon to find, entirely enclosed in the copper, masses of melaphyr, quartz, calcite or other vein materials; or, again, to find the copper entirely enclosed in some material. The melaphyrs themselves are often impregnated with copper adjacent to the veins. Good illustrations of the veins can be seen at the Phœnix, Cliff, Central, Copper Falls, and other mines in Keweenaw county.

(*e*) In the vicinity of Hancock, Houghton and Opechee, some of the old lavas are mined. As stated before, these old lava-flows, which now form melaphyrs (amygdaloids), have been greatly acted upon by water, and have had deposited in them different minerals associated with more or less copper. The copper is generally deposited in an irregular manner in the melaphyr, forming strings, globules, irregular masses, etc. These deposits are not in the form of veins, but are impregnations of old lava-flows, and hence are in the form of flow deposits. As an example of mines worked upon these old lava-flows there may be cited the Quincy, Franklin, Osceola, Atlantic, Huron, and, in part, the Copper Falls.

(*f*) The Copper Falls mine has been worked in part on an old lava-flow of a very scoriaceous character, that formed originally a black, rough, cellular lava sheet covered with clinkers, similar to many well-known modern lava-flows. At the time of the flow, or after it, the interstices were filled with detrital mud, while the various parts of the flow appear to be connected, and do not form true water-worn pebbles. The writer has collected at Copper Falls portions of the rock that show the hardened exterior crust and the cellular interior, as they occur in small masses and bombs of modern lavas, while he has found preserved intact the original ropy, stringy, twisted surface of the lava. The Copper Falls bed, above described, is locally called the ash-bed, but it is a melaphyr, or a true lava-flow, and not a bed of volcanic ashes. The Atlantic mine appears to be worked upon the same or a similar formation.

(*g*) Beside the veins and lava-flows, the conglomerates also have been found in places to have had their interstices filled in with copper and other minerals. In them the old cementing mud, and oftentimes the pebbles of melaphyr, have been removed by percolating waters, and their places filled with copper, which penetrates even the minute cracks in the hard rhyolite (quartz porphyry) pebbles. These old sea-beach conglomerates are now worked in the Calumet and Hecla, the Tamarack, the Allouez and other mines. There are thus mined in this region three distinct classes of deposits.

COPPER DEPOSITS OF KEWEENAW POINT.

§ 2. 1. Fissure veins.
2. Flow deposits (melaphyrs, or amygdaloids).
3. Conglomerates, or bed-deposits.

(*a*) These conglomerates are known to be old sea-beach deposits, like those that are forming along the lake or ocean at the present time. This is proved by the rounded and water-worn character of their pebbles and grains; by the observed water action on the surface of the underlying lava-flow; by the fact that at their base the conglomerates contain considerable basaltic mud and pebbles derived from the underlying lava, both of which diminish in amount or are entirely wanting as the distance from the underlying trap increases.

(*b*) That the copper was deposited from water, with or without electro-chemical action, is shown by the fact of its being found inclosed entirely in minerals known to be formed by water only; also by its enclosing such minerals; by its being found in disconnected or isolated masses in the lavas and elsewhere, and by its greater abundance where there are to be seen the most signs of water action. Had the copper been deposited by igneous agencies subsequently to the formation of the melaphyr and conglomerates, it would have had a channel or line of passage, and been continuous along that line of passage, while all the different masses of copper would have been connected together downward, unless separated by fractures or faults.

(*c*) The copper seems to have needed for its deposition the open spaces of veins and fissures, and rocks that were porous and cellular, or those whose parts were easily removed by the percolating waters, like melaphyrs or the cementing mud of the conglomerates. In truth, the copper seems to have been deposited wherever there were found any places in which to leave it.

(*d*) From the fact that the copper is generally found most abundantly under the heavy lava-flows, and associated with minerals evidently the product of the decomposed lavas, it appears probable that the copper was once finely disseminated through the lavas and has since been concentrated by waters percolating through them. This view is advocated by Muller, Bauermann, Marvine and myself, while a similar view has been advanced by S. F. Emmons to account for the origin and concentration of the Leadville ore deposits.*

Had the copper been derived from the sandstones, then one would suppose that under them should be found the greatest supply of copper, but such is not the case. That the course of water depositing the copper was generally downward is indicated by the finding of spikes of copper and calcite that extend from one bed down into others, with the small end downward like an icicle; by the fact that when the copper is not uniformly distributed throughout the bed or flow that is mined, it is often, although not always, more abundant in its upper portion; and by the fact that the largest masses of copper have usually been found in the upper portions of the veins.

(*e*) That the copper was deposited after the copper-bearing series was complete is shown by the fact that it is found in fissures extending across the beds, that could only have been produced after the beds were in place; by the fact that the copper was deposited subsequently to the jointing of the lavas, owing to its now being found wrapped around the pieces formed by jointing and by the extension of the copper from one flow down into another as a continuous mass.

(*f*) The means by which the copper was concentrated and deposited as native copper instead of occurring in the form of the usual copper ores, is an interesting, and as yet unsolved problem, that awaits the attention of the chemist who is willing to give his time and attention to the subject; although Pumpelly advocates the idea that the principal agent is the oxide of iron. In this he has much to sustain him, and his view is generally adopted.†

(*g*) The structure of Keweenaw Point may then be summarized as follows: A deposit of sandstone overlain by lava-flows mingled with more or less of interbedded conglomerates, and finally overlain by sandstone. Subsequently these beds suffered longitudinal and cross-fracturing and faulting. Later all were acted upon by percolating waters, both hot and cold, by which the rocks were altered to a greater or less extent, and the copper was concentrated and stored up in the conglomerates, lavas and veins in which it is now found.

The above account gives in brief a general idea of the geology of the regions touched upon here, as the writer interprets the facts observed. He is, however, aware that different interpretations of the same facts may be made by others. He has therefore called special attention to the important differences of interpretation, and he will endeavor to continue the investigation, and seek only the facts and the truths to which they point. As in the question of the iron ores, their origin has a direct bearing on their amount and the permanence of the deposit; so, too, in the copper-bearing rocks, the question of their relation to the Eastern sandstone is one of great economic interest in these days of diamond drills and deep shafts. One can readily see this when he considers that it involves the question: Do the copper-bearing rocks extend out under the Eastern sandstone or not? If they do, their exploration becomes merely a question of how great thickness of sandstone must be bored through. If they do not, then the question ought to be settled by the geologist, if possible, in order to save waste of money in unnecessary exploration on the part of those that are interested in mining.

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*Muller. Verhl. d. Natur. Gesel., Basel, 1854-57, pp. 411-438; Bauermann. Quart. Jour. Geol. Soc., 1866, XII 418 463; Wadsworth, Notes on the Geology of the Iron and Copper Districts, 1880, p. 126; Emmons, Geology and Mining Industry of Leadville, 1886, pp. 378, 379.

†Geol. of Mich. 1873, I, part II, p. 44.

CHAPTER IX.

MINERALS OF MICHIGAN.

§ 1. Under this head are placed some miscellaneous analyses and descriptions, as well as a list of minerals found in Michigan prepared by Dr. Lucius L. Hubbard.

(*a*) A very peculiar mineral. for which I am indebted to Capt. J. G. Cundy, occurs at the Champion mine (Beacon P. O.) and closely resembles picrolite, which it was considered to be until analyzed, by Prof. R. L. Packard, when it was found to have a composition closely like that of talc, but with a lower percentage of magnesia.

It seems to me to be an original mineral and not a pseudomorph. Its reported occurrence is such that it appears to have been deposited in the mine in a vein form. If it should be considered a pseudomorph, it is in my judgment allied much more in its structure to picrolite than to asbestus. The form is so peculiar and remarkable that I would propose for it the name of Beaconite, from the locality where it occurs. Below is given a description of this mineral, prepared at my request by Dr. A. C. Lane, in which are incorporated Professor Packard's analyses.

Dr. Lane reports as follows:

"The specimen seems to be a vein of asbestus bounded by a non-fibrous mineral of duller color; both are extremely soft."

"*Optical Properties:* Each part, when rubbed, separates into fibres which when immersed in water and oil show still noticeable refraction which must lie between 1.5 and 1.6.

"The bi-refraction is considerable. We may gain some conception of it by noticing the interference of colors of various small fibres, assuming that on the average their breadth will equal their thickness and, dividing the retardation necessary to produce this color by the thickness, we shall obtain *gamma minus alpha*. Thus we find,

fibre thickness mm^{-3}	25:	8:	3:	5:	10:	10:	25:	15:
color produced is that due to retardation of mm^{-6}:	700:	600:	250:	250:	300:	230:	500:	900:

which gives a mean double refraction (*gamma minus alpha*) of 0.044 with a probable error of .005.

"Owing to the flexibility and interlacing of fibres, the extinction is hard to determine with accuracy. It seems to be exactly parallel with the fibre axis, and positive (*c*).

"Two slides were made, one parallel with and one across the fibres.

"The slide parallel with the fibres shows that there is no essential difference between the fibrous and the non-fibrous mineral, as one shades into the other with parallel orientation, except that in the non-fibrous part there are many stray fibres.

"The fibrous portion is dotted with grains of magnetite just barely visible to the naked eye when attention is called to them (diameter about 0.1mm.) They do not seem to form over one-quarter of one per cent of the rock.

"The fibres have a peculiar shimmer when normal to the plane of incidence of reflected light; in transmitted light are cloudy and not very translucent; are slightly pleochroic, *gamma* being most absorbed.

"The duller part has, in spite of stray fibres, common orientation with that just described, and, being more translucent, lets a –bissectrix of moderate axial angle emerge (2 V=about 60°).

"(2) The section across the fibres magnificiently shows aggregate polarization (white in all positions).

"Small fragments that have tumbled on one side give the fibrous structure and bright colors with –bissectrix already noted. Owing to the aggregate character of the image in convergent light, the hyperbolas are not well developed.

"*Specific Gravity.* Four hasty trials on two different pieces (both of dull lustre) gave Sp. Gr., for the first 2.74 and 2.80; for the second 2.81 and 2.88.

"*Composition.* Prof. Packard made the following analyses:

Analyses.	Preliminary fibrous; per cent.	Fibrous; per cent.	Molecular proportion.	Dull; per cent.	Molecular proportion.
SiO_2	59.	59.72	.995	60.93	1.015
Al_2O_3	0.85	--------	--------	--------	--------
Fe_2O_3 & FeO	9.	8.67	.120	6.24	.088
MnO	0.87	0.64	.009	0.37	.005
MgO	25.27	26.42	.660	27.88	.697
Ignition	4.04	4.13	.230	4.67	.260
	99.	99.58	--------	100.09	--------

"Obviously these analyses suggest the formula $H_2(Mg,Fe)_3Si_4O_{12}$. The slight excess of base is partly due to the entangled Fe_3O_4. Fe:Mg in one case as 1:5, in the other nearly as 1:8. This is the formula of talc.

"*Comparison.* The analyses are like those under talc in Dana's System, fifth edition (especially No. 11), although unusually rich in Fe, but among the magnesia–iron amphiboles (No. 31, p. 237) and altered amphiboles and anthophyllites (p. 242) there are similar ones.

"Hardness and specific gravity and feel are those of talc. The fibrous character is not that of talc, but of asbestus. The optical angle is large for talc. This might be laid to the high percentage of iron.

"I should consider it then (unless field observations contradict) a pseudomorph of talc after asbestus,—a natural change, looking at their chemical formulæ."

(*b*) For purposes of comparison, the analyses made by Professor Packard of two picrolites are given here, No. 1 a specimen from North Carolina and No. 2 one obtained from the serpentine near the Ropes mine, north of Ishpeming.

	No. 1.	No. 2.
SiO_2	41.18	40.36
MgO	38.47	40.79
FeO	7.25	2.88
H_2O (ignition)	12.78	15.64
	99.68	99.67

(*c*) Analyses have also been made of a chloritoid and an amphibole, both from the Champion mine.*

No. 13,480 is the chloritoid analyzed by Dr. H. F. Keller and the gruenerite was analyzed by Mr. F. F. Sharpless.

	No. 13,480.	Gruenerite.
SiO_2	24.29	76.32
Al_2O_3	34.00	0.56
Fe_2O_3	10.55	0.99
FeO	20.51	6.96
CaO	0.61	----
MgO	1.29	12.47
MnO	trace	----
Na_2O	0.35	trace
K_2O	0.97	trace
TiO_2	0.28	----
H_2O	6.75	2.80
Specific gravity, 3.552.	99.60	100.20

(*d*) A rough partial analysis by Mr. F. F. Sharpless of a clay from Sec. 23, T. 46, R. 24, gave the following results:

Residue insolubile in H Cl	67.85
Moisture at red heat	1.49
Ca CO_3	25.43

This clay heated for one hour at a dull red heat lost 12.7 per cent of its weight, and turned slightly darker in color. It became slightly firmer than it was before heating. On further heating to a bright redness for thirty minutes it turned white, but remained solid and lost but little in weight. When heated to a white heat for ten minutes, it was entirely fused to a dull gray slag, but experienced only a slight loss in weight.

(*e*) A mineral oil purporting to have been obtained in cavities in dolomite and from the surface of pools on Sec. 34, T. 42, R. 21, was analyzed by Dr. H. F. Keller, who reports as follows:

"The sample separated, upon standing, into two distinct layers: the upper one, amounting to about 30 per cent of the whole, constitutes the mineral oil, whilst the remainder was found to be an aqueous liquid, holdin suspension a large amount of solid matter.

"The *oily layer* was carefully removed and each portion examined separately with the following results:

"The mineral oil is dark in color, displaying a strong green fluorescence, and has the smell and consistency of crude petroleum. Fractional distillation yielded three products:

		Per cent.
(*a*)	At and below 100° C	4
(*b*)	Between 150° and 300° C	36
(*c*)	Above 300° C	60

"Portion (*a*) separated into moisture and a very small quantity of low boiling hydrocarbons.

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* See. Zeit. Krystal., 1891, XIX., 383-385, and Am. Jour. Sci., 1891, XLII., 499-508.

"Portion (*b*) formed a clear yellow liquid, which did not solidify in a freezing mixture; it was too small for a satisfactory examination, but possessed the appearance of a good illuminating oil.

"The last fraction (*c*) was likewise clear and of a yellow color, and when placed in snow solidified completely to a white scaly paraffine.

"The *aqueous liquid* had an offensive odor and acid taste as well as a strong acid reaction. It was filtered from the suspended matter, but on standing, the clear solution again became turbid and afterwards gave a flocculent precipitate. A qualitative examination showed it to contain the carbonates of iron, manganese, magnesia, and lime held in solution by free carbonic acid. A smaller quantity of a volatile organic acid was also present; it was too little, however, to be identified. Neither chlorides nor sulphates were present.

"The suspended matter consisted chiefly of hydrated oxide of iron enclosing some of the oil and containing small amounts of peroxide of manganese and carbonate of calcium.

"The above results seem to show that the sample was a crude petroleum occurring in a ferruginous dolomite; too little is known, however, about this occurrence, and the quantity of material available was too small to admit of any definite conclusion."

(*f*) An analysis made by Prof. R. L. Packard, of water obtained from the Huron mine gave the following results:

Specific gravity 1.00647.
8.515 grammes solid matter to the liter,
496 grammes solid matter to the gallon.

The organic matter and insoluble residue were neglected, and the soluble material was found to have the following composition in 1,000:

		or	
Chlorine	4.739	Sodium chloride	4.021
Lime	1.9293	Calcium chloride	3.553
Magnesia	0.0493	Potassium chloride	0.163
Sulphuric acid	0.145	Calcium carbonates	0.056
Carbonic acid	0.079	Calcium sulphate	0.247
Soda	2.132	Magnesium carbonate	0.104
Potassa	0.103		

MACROSCOPIC MINERALS OF MICHIGAN.

BY LUCIUS L. HUBBARD.

§ 2. This list, compiled largely from lists heretofore published, contains some new occurrences observed in the field by members of the Survey, together with others noted in private collections.

For want of sufficient authentic material that would render possible a more detailed and instructive subdivision of localities, I have for this report, which is meant to be provisional, divided the Upper Peninsula into four principal sections: (1) The Marquette district, which includes Marquette and Baraga counties; (2) the Menominee district, which includes Menominee, Iron and Dickinson counties; (3) the Gogebic district; and (4) the Copper district, which includes Keweenaw, Houghton and Ontonagon counties and Isle Royale.

For their kindness in allowing me to examine their cabinets, I am indebted, among others, to Agents Daniell and Vivian, to Superintendent Evans, to Col. J. N. Cox and to Mr. J. W. V. Rawlings, all of this vicinity.

(*a*) LOWER PENINSULA.

Alabaster, amethystine quartz, anhydrite, apatite, aragonite, calcite, celestite, coal, dolomite, gypsum (including selenite), limonite, pyrite, siderite, sphalerite.

(*b*) UPPER PENINSULA.

Marquette District.

Native elements. Copper (Presque Isle—in small quantities, Huron Ids.—in granite), gold, graphite.

Sulphides. Bornite, chalcocite, chalcopyrite, galenite, pyrostilpnite pyrrhotite, sphalerite.

Oxides. Agate, cacholong, chalcedony, chromite, goethite, hematite, jasper, limonite, magnetite (lodestone), manganite, martite, psilomelane, pyrolusite, quartz, wad.

Silicates. Actinolite; albite (?), andalusite, anthophyllite (?), asbestus, *beaconite,*[*] biotite, chlorite, chloritoid (ottrelite), enstatite, epidote, garnet, *gruenerite, hisingerite,* hornblende, kaolinite, kyanite (?), magarite, muscovite, oligoclase (?), olivine, orthoclase, pyroxene (including diallage), serpentine (including precious serpentine, chrysotile, picrolite and williamsite), staurolite, talc, tourmaline, tremolite.

Various. Apatite, barite, calcite, dolomite, *melanterite,* molybdenite (Mich. Gold Mine), rhodocrosite, siderite (chalybite), scheelite, *sylvanite* (?).

Menominee District.

Sulphides. Chalcopyrite, pyrite.

Oxides. Quartz, hematite, limonite, martite.

Silicates. Laumonite, *malacolite,* orthoclase, *staurolite, tourmaline, tremolite.*

Carbonates. Azurite, calcite, dolomite, siderite, malachite.

Gogebic District.

Sulphides. Chalcopyrite, galenite, *marcasite,* pyrite, *sphalerite.*

Oxides. Hematite, jasper, limonite, *pyrolusite,* quartz.

Silicates. Feldspar, kaolinite.

Carbonates. Aragonite, calcite, dolomite, siderite.

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[*] Names in italics indicate minerals not heretofore reported by the Geological Survey.

Copper District.

Native elements. Copper, silver.

Sulphides, etc. Algodonite, bornite, cerargyrite, chalcocite, chalcopyrite, domeykite, pyrite, whitneyite.

Oxides. Agate, amethyst, cuprite, manganese (black oxide), melaconite, quartz.

Silicates. Analcite, apophyllite, babingtonite(?), chabazite, chlorastrolite, chlorite, chrysocolla, datolite (in crystals or massive), delessite, epidote, *harmotome*, heulandite, laumonite, leonhardite, mesotype, natrolite, orthoclase, pectolite, prehnite, saponite, stilbite, thompsonite(?), wollastonite.

Various. Ankerite(?), azurite, *barite*, calcite, malachite, *selenite*.

All other points in the Upper Peninsula.

Bog iron ore, calcite, dolomite, *fluorspar*, (N. of Nahma on Sturgeon River), gypsum (St. Ignace), siderite.

Following are the localities of recently reported minerals: Beaconite occurs at the Champion mine; gruenerite at Champion, Michigamme and Humboldt; hisingerite at Presque Isle; melanterite near L'Anse; malacolite and tremolite near the Metropolitan mine, Sec. 32, T. 42, R. 28; tourmaline on Sec. 2, T. 40, R. 30, Sec.s 25 and 35, T. 48, R. 28, and at the Jackson mine; marcasite and pyrolusite at Colby mine, T. 47, R. 46 (various manganese ores occur at different points in this vicinity); staurolite on Michigamme River, in Tp.s 41 and 42, R. 31; sphalerite in T. 47, R. 43; fluorspar on Sec. 4, T. 41, R. 19; scheelite on Sec. 20, T. 47, R. 30, Magnetic mine; sylvanite(?) reported by Mr. Ropes, north of Ropes Gold mine; selenite, National mine, Rockland; barite, Schoolcraft mine (now Centennial), also Phœnix mine; harmotome, St. Clair mine (specimen from collection of Col. J. N. Cox); thompsonite, Isle Royale.

MICROSCOPIC CHARACTERS OF ROCKS AND MINERALS OF MICHIGAN.

BY ALFRED C. LANE.

§ 3. (*a*) *Granite rocks.*—The granites of this region would mainly be classed as granitites. They are often crushed and then the distinction between them and gneisses or metamorphosed arkoses becomes very difficult, but considerable progress has been made in separating them.

The quartz porphyries become sericite schists, porphyroids or gneisses, whose truly igneous character is much obscured by a high schistosity or even a perfect cleavage. Much progress has been made in determining these rocks. (Williams, Bull. U. S. Geol. Sur., No. 62, p. 119). They are very numerous.

(*b*) *Syenites and Diorites* (Andesites).—These rocks are rare. They occur however, as well as do some very interesting dike forms, that fill up a gap in our present classification, and show an interesting parallelism in structure to the quartz diabases which are of course more basic in composition.

(c) *Quartz diabases.*—One of the most distinct groups which the petrographic work has isolated is that of the quartz diabases. The quartz in these rocks is almost never visible to the naked eye. In fact it often forms but a small portion of the rock. Yet its presence serves as a distinguishing mark.

These rocks are practically always in dikes, generally straight walled. They are often very fresh, and appear to be the youngest eruptive rocks in Marquette county. They often cut the upper Huronian slates and graywackes south of L'Anse, and it is highly probable that they are the dike forms corresponding to the Keweenaw lava-flows, for, (1) as they cut the Huronian they are younger than it; (2) practically similar rocks are at times found cutting the Keweenawan as dikes; and (3) they are not known to run up into the Eastern sandstone. This last fact may be used as an argument for the post Keweenawan age of the Eastern sandstone.

When they cut the greywackes and slates, they sometimes convert them into spilosites, such as have been described in Germany as resulting from the alteration of adjacent rocks by diabases. Where they cut quartzose layers, however, they are liable to change the latter into cherty bands, either making the black Lydian stone used by jewelers as a touchstone for gold, or at times forming banded rocks essentially like the jaspers and jaspilite of the iron formation. At the margins of these dikes the rock often is finer grained and glassy, tholeyitic. Such forms have a somewhat blue black lustre with glistening specks, and are of course massive. In such rocks no quartz can be seen, as it remains unindividualized in the glass. Such marginal bands are generally narrow and the main part of the rock is diabasic holo-crystalline and rarely ophitic. In such cases when the rock is fresh it is glassy in lustre, not dull nor silky as hornblende rocks are; is always massive, and of a dark, black or brownish grey color with white specks of glassy, more or less lath shaped, feldspar, that shows with a pocket lens twinning lines on the cleavage faces. In the thin section we see that the other components are magnetic iron ore, and a brown augite that has more or less of a violet tinge. All these components have at times their own crystalline shape, and the interstices between them I have called acid interstices. They are similar to those described by A. C. Lawson (American Geologist, 1891, VII, p. 153) from the Rainy Lake Region. Where augite comes in contact with these interstices it is coated with a dark brown hornblende, like basaltic hornblende and utterly unlike uralite. When feldspar adjoins them we can tell by its optical properties that from being at the center a lime-soda feldspar, like labradorite, the soda more and more predominates as we go toward the margin, until at the margin we often have growths springing out, to form with the quartz what is known as micropegmatite. These growths sometimes fill the whole remaining space. At other times there is some quartz in compact grains. Another curious feature of these interstices is that they are often crossed in all directions by needles of apatite—phosphate of lime. Similar needles sometimes occur (as at Capo di Bove, Rome and in the Eifel) in cavities of modern lavas. Folia of biotite often occur in the interstices near magnetite, sometimes evidently derived from it.

These interstices occur in their most characteristic forms in the freshest rocks, and their structure cannot be due to weathering nor to pressure, for it occurs in rocks which show no trace of pressure. It seems, and here I do not differ essentially from A. C. Lawson, that when the rock consolidated there were left interstices filled with hot alkaline water or dissolved water-glass which was probably the last residue of the lava, and of the steam and gases absorbed in it which had no chance to escape into the air from the dike as they would from a flow, and were under a pressure sufficient to prevent the formation of bubbles. Into these interstices the apatite needles grew, and the alkaline solution attacked the augite and magnetite, turning them into brown hornblende and mica. Finally the heated solution cooled, depositing the quartz and feldspar.

If this be true, the structure above is a strong evidence that the rock, which shows it, is an intrusive dike, even though the field evidence or field notes may not explicitly indicate the fact.

These intrusive dikes often cut the iron formation and are not infrequently met in iron mines. They seem to have assisted, especially by breaking up the formation and guiding the aqueous currents, in producing aggregates of soft hematite ore, but they are not the same as the miner's "diorites," which I call amphibolites, and have not the same effect in producing ore bodies, as they are presumably subsequent to the formation of the hard ore and magnetite bodies. When they are altered, however, they resemble these "diorites" and sometimes can hardly be distinguished from them. Generally speaking, however, they may be distinguished, even when weathered, by a dull color in the hand specimen, persistent traces of the feldspar laths, and under the microscope by the fact that not only is the augite changed to hornblende, but the feldspar is altered to epidote and sericite. They are rarely as uniformly altered as the amphibolites. Fresher specimens can almost always be obtained.

The great dike on Lighthouse Point at Marquette, which has also been described by Wadsworth* and by Williams (*l. c.* p. 138), may be taken as a type of these dikes, although it seems in some places to be more basic and bear more olivine and less quartz than they generally do. However, in its various modifications, it shows well the range of variation to be encountered in the group. Olivine, or its alteration product serpentine, may often be observed microscopically as an occasional accessory, especially in marginal forms, but is seldom abundant enough really to characterise the rock, and certainly is not characteristic of the group as a whole. Sporadically, however, olivine rocks do occur, but not of sufficient importance to be mentioned, except the two groups next treated. Our study of olivine rocks in general, however, tends to show that the alteration of the olivine is varied and not usually to serpentine, except in the peridotites. Talc, brown and green mica, iron oxides, actinolite, carbonates and quartz are among the decomposition products.

(*d*) *Lamprophyres*—Probably among the olivine rocks belong a group of dike rocks which have been found only in the neighborhood of Marquette, and only in a much decomposed condition. In them are numerous rounded pseudomorphs filled with carbonates and tremolite, which may have been olivine. The ground-mass is mainly of secondary minerals, tremolite, chlorite, carbonates, iron-oxides and leucoxene. Biotite and apatite commonly occur and may, perhaps, be primary, and very rarely chondritic aggregates of augite are preserved. In their ready decomposition and in what fragments of their structure remain, they show an affinity to olivine kersantites and the younger basanites, but in most cases the original character of the rock is a matter of remote inference, and the rocks can be uniformly named only by reference to their geological occurrence. These dikes occur abundantly on Partridge Island and Middle Island, T. 49, R. 25.

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*Notes on the Geology of the Iron and Copper Districts of Lake Superior, 1880, pp. 36, 37.

(*e*) *Serpentine*—Among the rocks that are classed as serpentines, one has been found that possesses peculiar scientific interest. It belongs to the group of troctolites, or forellensteins, being mainly composed of olivine and plagioclase with but little pyroxene. It occurs as an igneous vein in serpentine, and a careful revision of the literature leads me to the conclusion that this is the normal occurrence of the rock, and that troctolite stands to the other peridotites in somewhat the same relation that aplite, or pegmatite, does to granite. The specimen in question comes from the east side of Presque Isle near Marquette, (No. 11,861) 1,180 paces north, 1,300 paces west, Sec. 1, T. 48, R. 25.

Many of the so-called serpentines are more or less fresh peridotites,—picrite, hornblende picrite, lherzolite, and wehrlite. These rocks can also be followed in the process of weathering till they change into ferruginous dolomites.

Serpentine occurs typically at Presque Isle, on Sec. 36, T. 48, R. 28 and on Sec. 30, T. 48, R. 27.

(*f*) *Amphibolites and Hornblende-Schists.*—I find the distinction between these two rocks to be largely one for the eye, the hornblende schists being finer grained and more fissile, and the relations of the two being like those of the graywackes and slates. In almost all the rocks of this group I consider the hornblende to be uralite, i. e., to have been formed after the rock was consolidated, in large part replacing augite. It is this group of rocks that is so commonly associated with the iron ore, and has been commonly known by miners as "diorite." The name diorite is now applied by most writers to granitic rocks in which the hornblende is primary and not derived from augite, and at the time the name diorite was applied to these rocks the derivation of the hornblende from augite was not suspected. Even the quartz diabases were included under the name, their different composition, origin and structure not being noted. According to my opinion genuine diorites do occur, rarely, in the Marquette region, but they have no such relation to the iron ore as these products of metamorphic action which I call amphibolites. Comparing my nomenclature with that of others, I find that Wadsworth prefers to retain the name diorite, regardless of the origin of the hornblende, but that Williams (Bull. U. S. Geological Survey No. 62, Greenstone schist areas of the Menominee and Marquette regions of Michigan, p. 32) would separate from diorites these rocks with secondary hornblende, and call the latter greenstones, applying the terms epidiorite (p. 144) to uralitic quartz diabases, and saussurite gabbro (p. 68) to coarse varieties with decomposed feldspar, etc. (I am indebted to the kindness of Professor Williams and the officers of the U. S. Geological Survey for an opportunity to study the sections used to illustrate the Bulletin referred to). With the above explanation we generally agree in nomenclature, although occasionally Williams considers a hornblende as primary, classing the rock containing it with the diorites, while I should consider the hornblende as secondary and class the rock with the amphibolites. I cannot go quite so far as regards the granites, etc., as Irving does (Am. Jour. Sci., 1883, XXVI, pp. 17 and 321; 1884, XXVII, p. 130), yet I agree that all green hornblende of the older rocks should be looked at with suspicion.

How the amphibolites are distinguished from the diorites and what their relation to the iron ores is, is an important subject on which conclusions agreed to by all can not be considered as yet attained and the full evidence can not be here given. One important question is whether the change from gabbro and diabases to amphibolites is brought about by a mere rearrangement of the molecules without alteration in the composition, or whether there is at the same time a change in the chemical composition as a whole. It is generally conceded, for example, that in the change of pyroxene to hornblende the chemical composition does not remain exactly the same, but it is at the same time generally supposed that in the alteration there is merely a mutual exchange of elements among the minerals, so that the general chemical composition of the rock remains unaltered. In fact Rosenbusch bases one of his recent works on a fundamental principle (T. M. P. M., 1891, XII., pp. 51 to 52) that the crystalline schists are rocks changed by pressure (dynamo-metamorphosed), but without essential change in the chemical composition. He assumes of course that the quarry water helps in this change and that water, CO_2, and O may also be absorbed. Williams, too, in treating of these rocks, practically recognizes only weathering and pressure as efficient agents in their transformation. (Bull 62, U. S. G. S., pp. 41 to 43).

While I think this is true for some amphibolites, and especially for uralitic quartz diabases, yet, as it seems to me, there is too much variety in this group to grant that it is due merely to weathering, initial differences and pressure, even although we distinguish, as we must, between the effect of static pressure, and its kinetic effects, where the rocks have actually yielded, moved and been sheared. My optical investigations seem to show that in changing from augite the hornblende passes from an actinolitic variety towards glaucophane, that this change proceeds from the margin, and that it is accompanied by a fibrous outgrowth, which is in one case the rare mineral riebeckite. This would point to an increased percentage of alkalies. These often seem to have been absorbed from the feldspar, but in that case there must be a correlate production of zoisitic epidote. This is the case in saussurite gabbro, in the uralitic diabases, etc., but in a large class of amphibolites it is not true, and we are obliged to assume an actual increase in alkalies in the rock. This is confirmed by the change of olivine into biotite. Again, the ilmenite (or titaniferous magnetite) is replaced in the amphibolites by titanite, but not in equal abundance, and certainly not containing so much iron. Thus, it would seem that iron has been removed. Some small part of it might have been absorbed by the uralite, though authorities differ as to the probability of this. Iron oxide is often secreted in the uralite. But if we compare, in their analyses, hornblende schists in general with the augitic rock from which they are derived, we see that while the latter has more than ten per cent of iron oxides, the former generally have less, and the same thing is indicated by Teall's analysis of the Scourie dike in its fresh and in its altered form (British Petrography, p. 200). My observations, therefore, do not stand alone when I *suppose that in the formation of the amphibolites iron oxides were removed and condensed into ore bodies.*

(*g*) One of the most interesting results of field observations is that chlorite schists, which at times contain large, well-formed garnets, like those for which Michigamme is famous, and are studded with minute, sharp octahedra of magnetite, are at least sometimes but marginal forms of amphibolite bodies. Now, at the Champion mine we can see transitions from these chlorite schists to the ore bodies, as the magnetite grains which are usually isolated and porphyroidal become more and more frequent till they finally crowd together and replace the chlorite almost entirely. But while the iron oxide does sometimes replace the eruptive rock, that is by no means the universal rule. It impregnates the adjoining strata. While I would not deny that the original strata have been in some districts or in some places calcareous, i. e., composed of carbonates, or have contained iron to a considerable extent, in some other form than the carbonates, there is good evidence that the iron oxide does also sometimes replace quartz. Conglomorates have been saturated with iron so as to be worked to a limited extent for their ore, and the iron may be seen impregnating the pebbles from their periphery, and strata from their joints. The ore of the Volunteer mine seems in part to have replaced a sandstone. Whether the same agencies which introduced the iron may not also have converted the rest of the rock into a jasper, as the Arkansas novaculites have been formed, is a question.

I would not like to give my decided opinion as to what these agencies were. The evidence on which I would lay stress goes only to show that many amphibolites have been deprived of iron, and that some iron ore bodies have received their richness in iron as a pseudomorphic impregnation; at Champion, and probably in some other granular magnetite or martite bodies, replacing decomposed igneous rocks, but in other places replacing arenaceous stratified beds.

It may be that atmospheric weathering, and percolating surface waters have been the agents in collecting the iron. (Compare Kimball's account of the Cuban ores in A. J. Sci. 1884, XXVIII, p. 422 and 426.) Yet I would suggest the possibility that slowly percolating quarry-moisture-like alkaline solutions did the work. According to the theory of vein formation prevalent in America and upheld by such men as Newberry, Leconte and Becker, veins are mainly filled by deposits from ascending alkaline solutions. If this theory be true we may suppose that rocks are acted on by slowly percolating moisture, which may, perhaps (it is not essential to the theory) be given off by the earth in process of cooling, and gradually gather into veins as it approaches the surface.

This moisture could do the work required of it, i. e., supply the alkali to the uralite and the feldspar, and since iron, like magnesium, readily forms with alkalies soluble double salts, which are, however, exceedingly liable to precipitation by oxidation, it could remove the ferrous iron from the augite and ilmenite, to deposit it whenever it encountered an oxidizing agent. This would happen when it approached the surface or, perhaps, when it left the amphibolite to enter a more oxidized rock. The gruenerite may be due to the direct reaction of such moisture or quartz. Finally, alkaline waters could abstract or recrystallize silica.

According to this theory iron ore bodies formed in this way would occur: (1) in connection with masses of amphibolite, and (2) along the lines of flow of waters percolating out from them; waters whose course one cannot absolutely predict, though we should expect it to be upward or along bedding or cleavage planes, or along lines of much crushing and fracture where the rocks have been rendered permeable; (3) in general, therefore, stratigraphically above them, i., e. the "diorite" would be in the direction of the footwall; and (4) either near what was the surface at the time the basic igneous rocks were changing to amphibolites, (i. e., the unconformable contact between the upper and lower iron formations, the bottom of the upper iron formation being a quartzite or conglomerate) or in beds capable of precipitating the ore.

As these ore bodies are supposed to have been formed from ferrous salts, magnetite might often have been first formed and then replaced by hematite.

The full presentation of facts for and against this theory must be left to a more complete report. I do not suppose that it applies to all the ore bodies, especially not to the soft ores of the upper formation.

(*h*) *Spilites and andesites.*—Among the other basic rocks of interest is a group of spilitic and andesitic rocks associated with tufas which occur in the Crystal Falls region. They are microscopically marked by a great abundance of chlorite and of minute spherulites of silica. In the character of their alteration they approach the surface Keweenaw flows, from which I have as yet studied only sporadic sections, bringing out no new facts of interest.

(*i*) *Sandstones, arkoses, and quartzites.*—One feature of the sand-rocks, so far as I have studied them, is the large amount of feldspar they contain. This is true not only of the arkoses and quartzites where the feldspar is distinguished by its being in pinkish or whitish porcelain-like spots, or by its flashing cleavage facets, but also of the Eastern, or Potsdam sandstone. The analysis of the Portage Entry sandstone by F. F. Sharpless would indicate 37% of orthoclase, and a microscopic determination of the character of the grains in powder led to the same percentage.

(*k*) *Slates and graywackes.*—These rocks have been studied microscopically. The slates are the finer grained rocks that cleave readily, while the graywackes are the coarser rocks, generally massive or but coarsely fissile, composed of grains of sand (only in part quartz), which are imbedded in a slaty cement. This sedimentary group is to the unpracticed eye hard to distinguish from some eruptives, and we know of cases where eruptive dikes have been mistaken for graywacke bands, and a false idea of the dip acquired.

The graywackes are generally more of a bluish gray and more harsh and gritty under the knife than similar eruptives. There is no difficulty in distinguishing them under the microscope.

Almost without exception in every section of slates or of rocks that contain much slaty cement we find minute needles of tourmaline. These are without doubt formed in place and we can often see the sharp terminations to both ends. One end is terminated by $\frac{1}{2}$ R (Dana) or by the basis, and is often bluer than the other which is brown and terminated by R. (Dana).

The presence of these tourmaline needles is really characteristic of the slates, although they are sometimes so infrequent as to require looking for.

They do not appear to be so prevalent in the very graphitic bands that occur so frequently near L'Anse.

(*l*) *Minerals, chloritoid.*—The investigations of the Survey have shown that this mineral exists at various points, perhaps continuously, in a belt extending from Champion to Palmer. It exists in the various pebbles of conglomerate, occurs in quartzites, and in various schists of more or less obscure origin.

The investigation of this mineral by Dr. Keller and myself has led to the conclusion that many previous descriptions of it were optically and chemically faulty, and we hope to take up, as a separate piece of work, independent of the Survey, a general revision of the data for this mineral. Crystallographically and optically it is triclinic, and chemically it contains alkalies.

Localities where it occurs well developed are Humboldt, which is where it was first recognized by Dr. Wadsworth; about ½ M. south of Palmer; in drill cores from that neighborhood, where the rock is extremely like the Ottrez rock; and Champion shaft No. 1.

Among the observations where the mineral is nearly or wholly microscopic are the following:

(*m*) *Gruenerite.*—With the aid of a petrographic microscope it was recognized that the white or light colored amphibolite, which occurs often in the Marquette district in connection with magnetic iron ore, and has been called actinolite, i. e., a magnesia-lime-iron silicate, had the optical properties of gruenerite, a silicate of iron with more or less magnesia. This is confirmed by the analysis by F. F. Sharpless of impure material from the Champion mine. Further chemical investigation of this amphibole and the percentage of iron which it carries (it may run as high as 42½% Fe) is extremely desirable.

Localities for this mineral are the Champion mine and furnace, S. 31, T. 48, R. 29 and S. 7, T. 46, R. 29, and the Michigamme mine.

(*n*) *Perofskite*, in a chlorite schist, No. 6541, 1,250 paces N., 850 paces W., S. 13, T. 47, R. 47.

Fluorite, in a granite, No. 9615, 1,600 paces N., 450 paces W., S. 21, T. 42, R. 30, near the Milwaukee and Northern track.

Chlorite is very widespread. I have had occasion to study it as occuring after biotite, hornblende and augite, and to see it changing to biotite. I am inclined to believe that there is a continuous isomorphic series between it and biotite, and that the purer chlorite is optically positive. The isomorphic series is indicated, among other things, by the occurrence in chlorite of halos or spots which approach biotite not only in pleochroism but also in the strength and character of their birefraction.

(*o*) *Garnet* has been noted by previous writers as very widespread. It occurs in amphibolites, chlorite schists, mica schists, gruenerite and garnet schists. Once *cyanite* occurs with it (No. 11264 *a*, 1,400 paces N., 300 paces W., S. 31, T. 46, R. 39). The occurrence of an exceptionally *yellow* garnet at the contact of magnetite schist with granite (No. 8362, 1,600 paces N., 300 paces W., S. 30, T. 42, R. 28) is interesting.

(*p*) *Augite* is of course widespread. I have fixed more precisely than had hitherto been done the character of the dispersion, showing that the optical axis most nearly parallel to the prism axis is most dispersed, and that the pleochroism does not follow the axes of elasticity, but is most apparent in sections transverse to the prism.

(*q*) *Titanium minerals* are microscopically widespread. The alteration of ilmenite to rutile observed by Williams (Bull. U. S. Geol. Sur. No. 62, pp. 90 to 101) has been confirmed. Titanite can be followed, developing from ilmenite after passing through the amorphous leucoxene stage, and from augite as a bye product of uralitization. Much more remarkable and less known is the alteration of titanite to rutile and carbonates (No. 1069 *b*, 300 paces N., 1,630 paces W., S. 9,T. 48, R. 25).

The description of *types of structure* can hardly be attempted without diagrams. However, two structures characteristic of the metamorphic rocks, the pseudoporphyritic where one mineral occurs in large, well defined crystals, and the cellular structure (often combined with the pseudoporphyritic) in which the larger crystals are riddled with enclosures commonly quartz, have been observed in chloritoid, siderite and dolomite, garnet, hornblende, brown and white mica, chlorite and epidote. They are known to be characteristic of chloritoid, but have not been so widely recognized as belonging to some of the other minerals.

MICROSCOPIC STUDY OF SOME MICHIGAN ROCKS.

BY HORACE B. PATTON.

§4. The work which I have been engaged upon has been chiefly the study and detailed description of thin section of rocks, collected mainly in the Marquette and Menominee Ranges. Of these I have described upwards of two thousand.

Crystalline schists and eruptive rocks form naturally the great bulk of the rocks described. The former may be classified as gneisses, amphibolites, schists and slates. But comparatively few gneisses have been met with. The slates pass into greywackes and quartzites, both of which are very abundant among the rocks described. Among the *schists* the following varieties have been named and described. For brevity's sake the name schist is omitted after each name: Biotite, biotite-quartz, biotite-chlorite, micaceous hornblende, chlorite, chlorite-mica, chlorite-mica-epidote, feldspathic chlorite, porphyroidal biotite, porphyroidal chlorite, porphyroidal biotite-chlorite, magnetite-chlorite, actinolite, epidote-actinolite, hornblende, hornblende-biotite, gruenerite, calcareous actinolite-chlorite, calcareous chlorite, sericitic chlorite, sericitic quartzose, staurolite, staurolite-sillimanite, staurolite-biotite, garnet-mica, garnet-chlorite-actinolite, conglomerate, carbonaceous chlorite, ferruginous sericite, hematite-quartz, and others.

The *slates* and *greywackes* are likewise very abundant. They appear frequently greatly metamorphosed, sometimes, probably by contact, usually by regional metamorphism. One of the most interesting alteration forms is that of the above mentioned porphyroidal chlorite, or porphyroidal biotite schists, in which large, well formed crystals of biotite and of chlorite, themselves porous and filled with inclusions of quartz, etc., lie imbedded in a fine grained chlorite-quartzose schist or slate.

In many cases it is impossible to draw the line between the certainly sedimentary and the schistose rocks. To some of the more thoroughly crystalline, feldspathic-schistose rocks, apparently of sedimentary origin, the name dense gneisses has been applied.

Among the *eruptive rocks* the most abundant are the diabases, porphyrites, granites, syenites and diorites, with only occasional peridotites.

Very few of the granitic series show well preserved granitic structures. Most of these have suffered both mechanical deformation and far reaching metamorphic alteration.

In the fine grained, more basic eruptives, this alteration process has gone much further. Most of the porphyritic rocks were originally fine grained eruptives of a spilitic type, i. e., containing but few large porphyritic crystals. The augite mineral has nearly always been first altered to hornblende and this has further been changed to chlorite. The feldspars are also altered to chlorite alone or to chlorite and fine needles of nearly colorless actinolite. The rock, in its more advanced stages of alteration, shows no trace of the original ingredients, and yet in almost every case, even when a marked schistose structure has been produced, traces of the original structure can be seen in the arrangement of the matted actinolite and chlorite particles, more readily, however, by the arrangement of others less abundant, but always present products of alteration, namely, iron oxides and leucoxene.

The ultimate form which these altered porphyrites take is that of a chloritic or actinolitic schist.

The following is a brief description of a few groups of the more interesting rocks upon which I am engaged. The full description will appear in the final report.

(*a*) *Dike rocks.*—Among the eruptive rocks of the Marquette Range are a few that occur in dike form, which, on account of their unusual structure, merit special attention. Closely related to these, structurally, are others which are probably also dike rocks, although the field notes do not make this evident.

Perhaps the most noteworthy of these rocks is No. 11727, which occurs in narrow veins or dikes located 555 paces N., 5 paces, Sec. 14, T. 48, R. 25. To this rock the name *aplitic* diorite has been given.

In mineral composition the rock is a diorite, as it consists principally of plagioclase, brown biotite and green hornblende. Orthoclase, microcline and quartz are also abundant, but they are decidedly subordinate to plagioclase.

In his classification of the dike rocks Rosenbusch describes three types of rocks, two of which are porphyritic, i. e., have one or more of the ingredients occuring in an older and in a younger generation, while the other, though not in this sense porphyritic, shows its principal minerals occurring in well defined, or at least partially developed idiomorphic forms. In this latter group of his dike rocks, Rosenbusch places only the aplites, which are mineralogically equivalent to the granites.

In this third type belongs No. 11727. It contains sharply developed lath-shaped plagioclases that have clouded centres and clear, more acid margins. Between these plagioclase laths occur allotriomorphic grains of orthoclase, microcline, occasionally of microperthite and of quartz. The last named not infrequently forms micropegmatitic intergrowths with the feldspar, and occurs in irregular, seldom roundish grains.

The biotite and hornblende occur in clusters of small grains which show approximately idiomorphic, but not so sharply defined, forms as does the plagioclase.

It is evident that this rock has not the same structure as is to be seen in most aplites. It resembles rather those less common aplites that incline towards a porphyritic structure, but as no recurrence of crystallization is to be noted in this rock, it can not be classed with the porphyritic types of dike rocks.

A somewhat different structure occurs in certain rocks that closely resemble each other and apparently belong to this division of the dike rocks, found on Middle Picnic Island, (Nos. 848 a, and 848 b) T. 48, R. 25; and in T. 42, R. 32 (Nos. 10039, 10040).

(*b*) *Diabase altered to kaolin and quartz.*—The iron ores in the region around Ishpeming are frequently cut by dikes of diabase so thoroughly altered as to be no longer recognizable except by their dike form. Nos. 13456, 13458 and 12459 are specimens taken from a dike cutting the ore in the Lake shaft at the Cleveland mine. No. 13456 is still quite fresh, of a dark gray color, weathered brown on the surface, and shows under the microscope the customary structure and composition of diabases. No. 13459, on the other hand, is a white, earthy, kaolin-like mass. The intervening numbers resemble the latter, but are stained with brown oxide of iron.

Under the microscope this kaolin-like rock shows very well preserved the diabase structure of No. 13456, but in place of the plagioclase laths and the augite grains there is a white, earthy substance with interspersed colorless quartz grains, as well as black magnetite. The magnetite presents about the same appearance as in the unaltered rock, and is evidently the only ingredient that has not been altered. A chemical analysis of this rock, made by Mr. Fred F. Sharpless, shows that it is composed of about 79 per cent kaolin and 20 per cent free quartz (magnetite and impurities amounting to 1 per cent).

It appears that in the process of alteration Na, Ca, Mg and Fe, as well as SiO_2, have been removed and H_2O has largely increased.

(c) *Hornblende picrite.*—This member of the not very frequently occuring peridotite family is one of the most interesting of the rocks I have described and has therefore been the subject of more than usual study.

The hand specimen shows a very coarse grained, massive rock of dark green, almost black, color. It contains numerous large lustre-mottled grains of black hornblende.

This mineral, as seen under the microscope, is the most abundant and characteristic ingredient in the rock. The lustre-mottling is caused, as might be expected, by enclosures of nearly colorless olivine grains. The form of the hornblende grains is quite allotriomorphic; its color a deep rich brown. The pleochroism is exceptional, inasmuch as the brownest color is that of rays of light vibrating parallel to the ortho-diagonal axis. It contains countless enclosures of long opaque rods and brownish plates which exactly resemble those frequently met with in hypersthene.

In fact, the hornblende itself resembles hypersthene to a remarkable extent, so as to be readily mistaken for that mineral. The only pyroxene present in abundance is a greenish to colorless augite.

The feature which makes this rock of special interest, however, is the presence of what have been called "reactionary bands" or zones around the olivine grains wherever these came in contact with the sparingly represented plagioclase.

Those "reactionary bands" consist usually of two zones, an inner, very narrow and sometimes entirely wanting zone, and an outer, broader irregular zone. The former appears to consist of an orthorhombic pyroxene, the latter of grains of a light green hornblende.

Although these bands are confined to the contact of olivine with plagioclase, wherever augite is to be found in the immediate neighborhood it appears to have exerted an orienting influence on the orthorhombic pyroxene and on the hornblende of those zones.

Around the augite, when in contact with feldspar, there is also a band, but this forms but one zone, which consists to all appearance of the same light green amphibole which forms the outer zone around the olivine.

This rock is very closely allied to one described by Williams from the "Cortlandt Series" on the Hudson river near Peekskill, N. Y. (Amer. Jour. Sci., 1886, Vol. XXX., p. 35). The "reactionary bands" indicate that it has been subjected to powerful metamorphic influences.

The number of this rock is 7342; it is located 1,250 paces N., 1,950 paces W., Sec. 28, T. 42, R. 31.

PROPERTY

OF THE

MICHIGAN GEOLOGICAL SURVEY.

LIST OF GAS AND SALT WELL SECTIONS READY FOR PUBLICATION.

EXHIBIT L.

LIST OF GAS AND SALT WELL SECTIONS READY FOR PUBLICATION.

Adrian Gas Co.
Algonac, Albert Miller.
Algonac, Algonac Salt Co.
Alpena, Alpena Co.
Bay City.
Benton Harbor Natural Gas and Oil Co.
Charlotte, Eaton Co.
Clifford Oil Co.
Coldwater, Branch Co.
Constantine, St. Joseph Co.
Corunna, Corunna Coal Co.
Courtwright, Ontario.
Delphi, Carroll Co., Ind.
Detroit Natural Gas Co.
Dowagiac, Round Oak Gas and Fuel Co.
Elkhart, Elkhart Co., Ind.
Frankfort, Benzie Co.
Goshen, Elkhart Co., Ind.
Grand Rapids Artesian Well Co.
Grand Rapids No. 2.
Imlay City, Walker & Co.
Jackson, Worthington & Cooley Mfg. Co.
Jackson No. 2.
Jackson No. 3.
Kalamazoo, Kalamazoo Natural Gas Co.
Ludington, Pere Marquette Lumber Co.
Ludington, Butters & Peters (2).
Ludington, Peters's old well (3).
Manistee No. 1, Sand's well.
Manistee No. 2, Cranfield & Wheeler.
Manistee No. 3, R. G. Peters.
Marine City No. 1, Leoter & Roberts.
Marine City No. 2, Baird Bros.
Marine City No. 3, Curtis & Lester.
Marine City No. 4, National Salt Co.
Marine City No. 5, W. B. Morely.

Marine City No. 6, O. W. Owen.
Marine City No. 7, Marine City Well.
Marysville, Church & Co.
Monroe Well, Monroe.
Muskegon, Mason Lumber Co.
Niles, Berrien Co.
Owosso, Shiawassee Co.
Petrolia, Canada.
Pontiac Natural Gas and Oil Co.
Port Huron No. 1, C. A. Bailey No. 1.
Port Huron No. 2, C. A. Bailey, No. 2.
Port Huron No. 3, C. A. Bailey No. 3.
Port Huron No. 4, Chadwick Well.
Port Huron No. 5, T. J. Gordon.
Port Huron, Henry Howard Well.
Port Huron, Junction Well.
Port Huron No. 8, McMoran No. 1.
Port Huron No. 8, McMoran No. 2.
Port Huron No. 1, F. L. Wells.
Port Lamberton Salt Well.
Royal Oak No. 2, Mfg. Gas Co.
South Bend, Oliver Chilled Plow Works.
St. Clair, St. Clair Salt Works.
St. Clair No. 2, Oakland well.
St. Ignace, Mackinac Lumber Co.
Stronack, Stronack Lumber Co.
Wyandotte, Wayne Co.

Cross Sections.

No. 1, Niles to Bay City. A—B.
No. 2, Hillsdale to Bay City. C—D.
No. 3, Detroit to Saginaw. E—F.
No. 4, Niles to Frankfort. G—H.
No. 5, Muskegon to Charlotte. J—K.
No. 6, Monroe to Port Huron. L—M.

Geological Column for Southern Michigan.

Maps, Field Books, etc.

One large Map of Iron Regions of Michigan, partly completed.
Two railroad maps of the Northern Peninsula (eastern part), backed.
One map Northern Portion of Michigan, backed.
One map Michigan Land and Iron Co., backed.
One Winchell's Geological Map of Michigan, backed.
Two Canal Co. maps of Menominee Iron District, one backed.
One hundred and eight pen and ink sketches (W. L. Honnold and A. E. Seaman).
One Rominger's Geological Map of the Lower Peninsula of Michigan.
One Emerson's Map, Portage Lake Mining District, backed.
Three hundred and ten tracings from Township Plats.
One hundred and twenty-five blank Township Plats.

One hundred and forty sheets 4 Tps., partly completed maps.
One map Military Road Lands.
One railroad map, Central Portion of Upper Peninsula.
One map of Presque Isle.
One railroad map of Northern Peninsula, as far west as range 38.
Two maps, Portage Lake Mining District (revised edition).
Four Plat Books, containing plats of townships in Upper Peninsula.
Three catalogues for Rocks gathered by Survey (A′, A, and B).
Forty-four Field Note Books, containing notes. } Bound in leather.
Twelve Field Note Books, blank.
Four books containing records of salt wells, bound in canvas.
Seven blank books (A to G) for records—one partly filled.
Sixty desk pads.
Twenty-one reams typewriter paper.
Ten reams Crown Leghorn.
Eleven reams Victor.
One hundred and ninety sheets ruled map paper, large size.
Fifteen thousand seven hundred catalogue cards.
Two thousand printed labels for rocks.
A quantity of voucher blanks.
A quantity of manuscript notes.
Card catalogue of the Geology of Michigan, partly completed (W. L. Honnold).
A quantity of literature cards for petrography.
A quantity of library cards.
One Remington typewriter and oak desk.
One micro-photographic camera.
Nine cabinets of ten drawers each, for holding microscopic slides.
Eight pine cases, 42x24x18 inches, containing ten drawers each.
One map case, 42x28x25 inches, containing three drawers.
Four pine tables.
Two revolving chairs, wooden bottoms, with cushions.
Two cane seated chairs.
Four microscopes, each with objectives, professional ($1\frac{1}{2}$ in., $\frac{1}{2}$ in., and $\frac{1}{8}$ in.), two eye-pieces (2in. and 1 in.), also four plates, (quartz wedge, $\frac{1}{4}$ und. plate, red first-order plate, and Bertrand lens), with each instrument. (Bausch and Lomb).
One 3–6 in. objective. } Extras.
Two Bertrand eye-pieces.
One microscope with objectives, (1 in. and $\frac{1}{4}$ in., iris diaphragm, gypsum plate), and common accessories. (Acme).
One Westphal balance.
Three dip compasses. (Gurley).
Two dial compasses. (Gurley).
One aneroid. (Pitkin).
One diamond glass-cutter.
Six thousand two hundred and fifty specimens of Michigan rocks.
Six thousand two hundred and ninety-three microscopic slides of Michigan rocks.
Fifty-seven microscopic slides for reference (minerals and rocks).
One kerosene lamp.
Two pairs tweezers.
One glass plate, 14x16 inches.

Six tubes Canada balsam.
Seven oz. No. 1, 1 in. squares.
Four and one-half gross slides 2''x1.''
Two hundred and fifty slides 3''x1.''
Twenty-five pounds emery.
Two bottles diamantine.
One tube black paint.
One tube cobalt.
One and one-half boxes Esterbrook's chancellor pens.
One-quarter box Gillot's pens.
One and three-fourths doz. No. 6 Faber's pencils.
Two doz. No. 4 Faber's pencils.
One-quarter doz. Dixon's secretary pencils.
Seventy-five colored pencils (Faber's).
One sponge cup.
Three pen holders.

Field Equipment.

Two wall tents (damaged).
One fly tent.
Six pair blankets (all worn).
Four pack sheets.
Twenty small sacks.
Five large sacks.
Two tin bakers.
One frying pan.
Six iron forks.

Six iron knives.
Four iron spoons.
Four iron teaspoons.
One set camp pails.
Fourteen tin plates.
Six tin cups.
Three tin basins.
Five sets pack straps.
Two small axes.
One pick (miner's).
One shovel.
One large sledge hammer.
Two picks (explorer's).

I, A. E. Seaman, do hereby certify that the foregoing is substantially a true and complete inventory of the property belonging to the Geological Survey of Michigan in the custody of the State Geologist, and that the same is now in the possession of the Survey, at the Michigan Mining School at Houghton.

Houghton, Mich., Oct. 13th, 1892.

A. E. SEAMAN,
Assistant Geologist.

Attest:
M. E. Wadsworth,
State Geologist.

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